

INITIAL ELASTIC AND FRICTIONAL  
BEHAVIOR OF METAL INTERFACES

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Leslie J. Williamson



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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Cambridge 39, Massachusetts

May 23, 1955

Secretary of the Faculty  
Massachusetts Institute of Technology  
Cambridge 39, Massachusetts

Dear Sir:

In accordance with the regulations of the Faculty,  
I submit herewith a thesis entitled "Initial Elastic  
and Frictional Behavior of Metal Interfaces," in partial  
fulfillment of the requirements for the degree of Master  
of Science (without specification).

Respectfully yours,

Leslie J. Williamson  
Lieutenant, U.S. Coast Guard

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BEHAVIOR OF METAL INTERFACES

by

LESLIE J. WILLIAMSON  
Lieutenant, U.S. Coast Guard  
B.S., U.S. Coast Guard Academy  
(1945)

SUBMITTED IN PARTIAL FULFILLMENT OF THE  
REQUIREMENTS FOR THE DEGREE OF  
MASTER OF SCIENCE  
(without specification)

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY  
(1955)

Signature of Author .....  
Department of Naval Architecture and  
Marine Engineering, May 23, 1955

Certified by .....  
Thesis Supervisor

Accepted by .....  
Chairman, Departmental Committee on Graduate Students

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BEHAVIOR OF METAL INTERFACES

Leslie J. Williamson  
Lieutenant, U.S. Coast Guard

Submitted to the Department of Naval Architecture  
and Marine Engineering on May 23, 1955, in partial  
fulfillment of the requirements for the degree of  
Master of Science

ABSTRACT

The object of this thesis is to investigate the reported existence of abnormal elastic effects in metal interfaces. In conjunction with this work, the initial frictional behavior at the metal interfaces was observed.

The method of investigation selected employed hollow cylindrical specimens composed of two mating parts placed end on end. The experimental apparatus utilized a combination of optical and mechanical means of measuring small angles of twist in the specimen. Various metals were tested under different conditions of normal load and surface finish.

Excellent conformity between observed values of twist and those predicted by elastic theory was achieved. The experimental results did not show any indication of excessive elastic angles of twist.

Investigation of the initial frictional behavior of the metal interfaces indicated that the value of the friction coefficient increased with incremental changes in the observed slip until the range of normally expected values was attained. In this range the curve flattened out and free sliding resulted.

In view of the results of this investigation, it is believed that the reported abnormal elastic conditions were the result of inaccuracies in the experimental method, and that further investigation along this line is not warranted.

Thesis Supervisor: Brandon G. Rightmire

Title: Associate Professor

BEHAVIOR OF METAL INTERFACES  
INITIAL PLASTIC AND FRICTIONAL

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valued at the time of the investigation and the value was  
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Further investigation along this line is not warranted.

These authors



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To Professor Brandon G. Rightmire, who kindly consented to supervise this thesis, I wish to express my sincere appreciation of his helpful suggestions and encouragement during the course of the research.

I wish also to thank the members of the Lubrication Laboratory for their co-operation.

Finally, to Bertha Hornby, who typed the thesis, go my thanks for her careful work.

## APPENDIX

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## I. INTRODUCTION

In a thesis,<sup>(1)</sup> Coyle and Stromberg reported the existence of abnormal elastic effects in metal interfaces. As a result of their work, they concluded that the asperities in steel interfaces contribute materially to the elastic twist. The elastic twist due to an interface appeared to decrease with increase in normal stress for a given value of maximum tangential stress. They also found that the effect of surface finish was affected by normal stress, in that a transition range existed for normal stress. This transition range separated the regions where elastic twist increased or decreased with the degree of surface finish. This appears to be a virgin investigation of elastic effects in metal interfaces, as a survey of the literature failed to disclose any previous work along this line.

Tomlinson, Thorpe, and Gough,<sup>(2)</sup> in a paper on fretting corrosion, reported that surfaces in contact under normal and tangential stresses have a comparatively high degree of tangential elasticity. "The surfaces appeared to yield under tangential stress in an elastic manner by an amount which may be many times greater than the smallest slip it is hoped to detect." This made their problem of measuring slip extremely difficult. In the second phase of this investigation, this problem was encountered where the displacements measured were of the same order of magnitude as the depth of the asperities

I. Introduction

In a study, [1] by [2] and [3] reported the following at chemical effects in metal systems. As a result of their work, they concluded that the separation in metal systems is essentially independent of the chemical nature. The chemical nature has an influence upon the separation with increase in metal effect for a given value of chemical nature. They also found that the effect of various chemical elements is small, in that a separation value existed for each element. This separation value appeared the various chemical nature increased by increasing the degree of metal effect. This appears to be a slight modification of chemical effects in metal systems, as a result of the literature failed to discuss any previous work along this line.

Tamplin, [4] and [5] in a paper on "The separation of metal systems in metal systems" reported that separation in metal systems is independent of the chemical nature. The separation appeared to be independent of the chemical nature in an element system by an element which may be used to separate the metal and it is found to be independent of the chemical nature of the metal. This work is a result of the separation of metal systems in metal systems. In the second phase of this investigation, the separation was reported that the separation of metal systems is independent of the chemical nature of the metal.



in the metal interfaces. The first objective of this investigation was the development of a test apparatus and an experimental procedure of sufficient sensitivity and accuracy so that the existing discrepancies between calculated theoretical and observed values of elastic twist would be eliminated or rationalized. Various methods of measuring elastic twist in a specimen were considered, as discussed in Appendix A.

The second phase of this work was a by-product of the original investigation. After extensive examination of the elastic effects at metal interfaces under various conditions of load and surface finish, it was decided that a study of the frictional behavior would be both interesting and valuable.

Experimental research would be well interesting and valuable.

Of such and various kinds, it was decided that a study of the classic effects of early language upon verbal development and language acquisition, other extensive knowledge of the language itself of this sort was a by-product of the research was necessary, as discussed in Appendix I.

Extensive knowledge of language itself was in fact necessary. Extensive knowledge of language itself was in fact necessary. Extensive knowledge of language itself was in fact necessary.

As the work continued, the first objective of this research was to determine the effect of early language upon verbal development and language acquisition.

## II. PROCEDURE

The test apparatus used in this work is illustrated in Figures I, II, and III.

The tubular specimens tested were machined from the following materials: (1) AISI C-1018, cold-finished, open-hearth, low-carbon steel; (2) AISI A-4140, heat-treated, stress-relieved, medium-carbon alloy steel; (3) hard-drawn, electrolytic, tough pitch copper rod; (4) 2S Aluminum.

The specimens were reamed out to an inside diameter of 0.191"; then turned down to 0.236" outside diameter. The test specimens were cut into two halves, each one inch long. A single two-inch specimen was made for each material, and used as a control specimen. The observed deflections of the control specimen ( $\psi_o$ ) were compared with the computed deflections ( $\psi_c$ ) as predicted by elastic theory, thus providing a check of the accuracy of the test runs. The effect of the interface could be determined by a comparison of control-specimen runs with test-specimen results.

The upper and lower halves of the test specimen are mounted as shown in Figure III. The contact surfaces were lapped to the desired finish with emery polishing paper of varying degrees of roughness. The specimen was clamped in a vee-type block during the polishing process, to insure that the test surfaces were ground perpendicular to the specimen axis. The specimens were carefully cleaned both before and after the



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707-8795. Please contact the following address, or further information.

0-17 86290-0 were placed immediately in the specimen can.

The specimens were carefully cleaned before use and after use.

polishing process. (Reagent acetone was used as cleaning solvent.)

Two double-ended indicator arms were used, one on either side of the interface. Each arm was constructed with two 12" lengths of Type 321 stainless-steel tubing having 1/8" outside diameter and 0.005" wall thickness. The indicator arms were fastened to the specimen by a collar, as shown in Figure III. The cone-pointed set screws were used to obtain a knife-edge line from which the twist was transmitted. The pin-point indentations produced on the specimen by the set screws permitted length "L" to be accurately picked off the specimen with draftmen's dividers.

The alignment jig shown in Figure III was used to insure that the face of the indicator-arm collar, hence the plane of the set screws, was perpendicular to the axis of the specimen.

The lower half of the specimen rests on a machined and polished steel plate. For initial tests on the steel specimens a machined steel block was used, as shown in Figure I (1). The remainder of the specimens were mounted on the machined steel block shown in Figure III. This block has a securing collar which permits clamping of the bottom end of the specimen. After a final cleaning of the two contact surfaces, the upper half of the specimen was placed on the lower portion, and the weight rod then run up through the annulus of the specimen. The weight release (screw jack) permits the weight pan support rod to be run up and down as desired.





The threaded upper end of the rod was then screwed into a circular disc, separated from the top of the specimen by a ball thrust bearing as illustrated in Figure III. This bearing was used to isolate the specimen from any torsional vibration or movement of the normal load weight pan.

The sight edges are pictured in Figure I (2) and Figure III. The two sight edges were polished with 4/0 paper so that a clean, sharp sighting surface was obtained. Alignment of the two sight edges could be obtained by loosening either one or both of the clamp screws, and moving the edges into position as desired. The upper arm sight edge strip was cut wider than that on the lower arm. The distance from this edge to the center of the indicator-arm collar was measured accurately (12.33"), giving length "R". With the microscope focused sharply on this edge, the other sight edge strip was brought into focus by bending it slightly.

The torque arm was aligned so that the silk threads transmitting the forces from the torque weight pans are perpendicular to the lever in both horizontal and vertical planes. The pulleys were adjusted in both vertical and horizontal planes by moving pulley clamps on the support rods, as shown in Figure II. When alignment of the torque system was obtained, the torque arm and pulley support clamps were locked in place with their set screws.

The desired normal load was placed on the weight pan and then applied to the specimen by cranking down the weight release.

The zero reading of the indicator arms was then recorded.

the physical and mental health of the community.

tion or movement of the nose I find weight loss.

The slight edges are pictured in Figure 1 (a).

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with their own views.

The subject named said was placed in the subject's room and  
then applied to the physician in waiting for the subject's release.  
The new reading of the information given was then reviewed.

By adding equal weights to the two weight pans, a known torque was applied to the specimen and the resulting twist was measured on the optical micrometer. After each reading the torque was removed and the zero reading recorded.

After measuring the distance "L" between pin-point indentations in the specimen, these pits were marked so that they could be distinguished from marks made in the succeeding test.



By making slight changes in the two weight means, a better balance was obtained in the specimens and the resulting detail was improved on the vertical dimension. It may have resulted in a better balance and the new design was adopted.

... The following are the names of the persons who were arrested in this case:

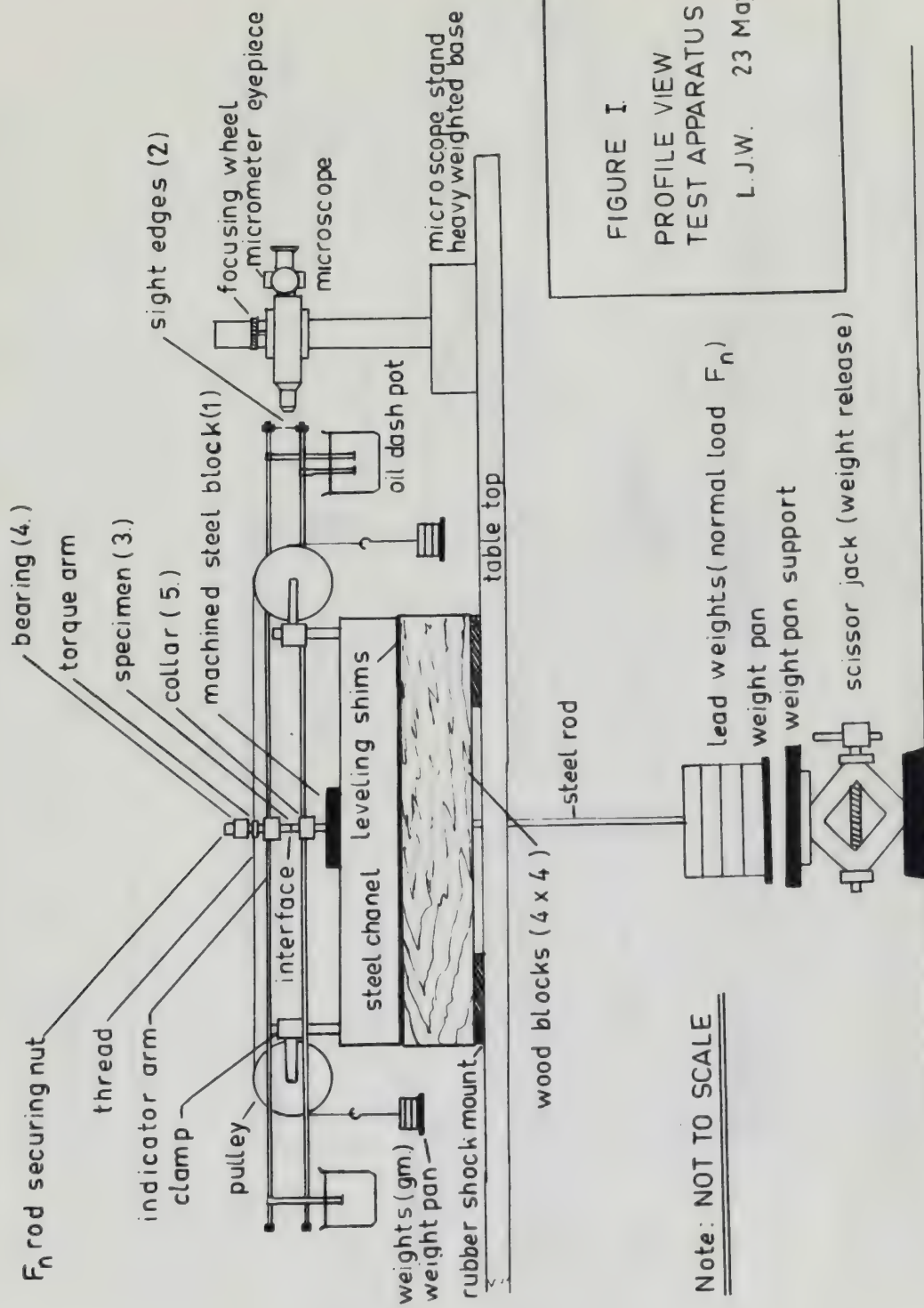


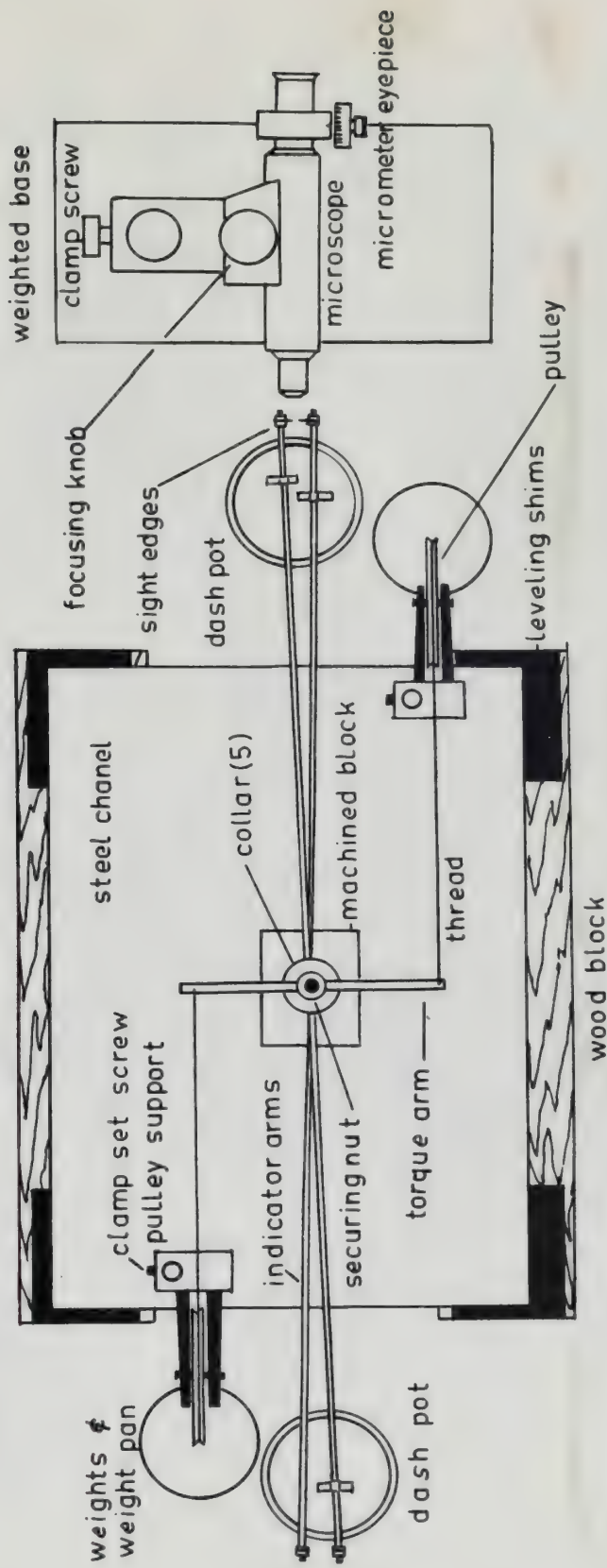
FIGURE I  
PROFILE VIEW  
TEST APPARATUS

L.J.W. 23 May, 1955





FIGURE II.  
PLAN VIEW OF TEST APPARATUS



Note: NOT TO SCALE

L.J.W. 23 May, 1955



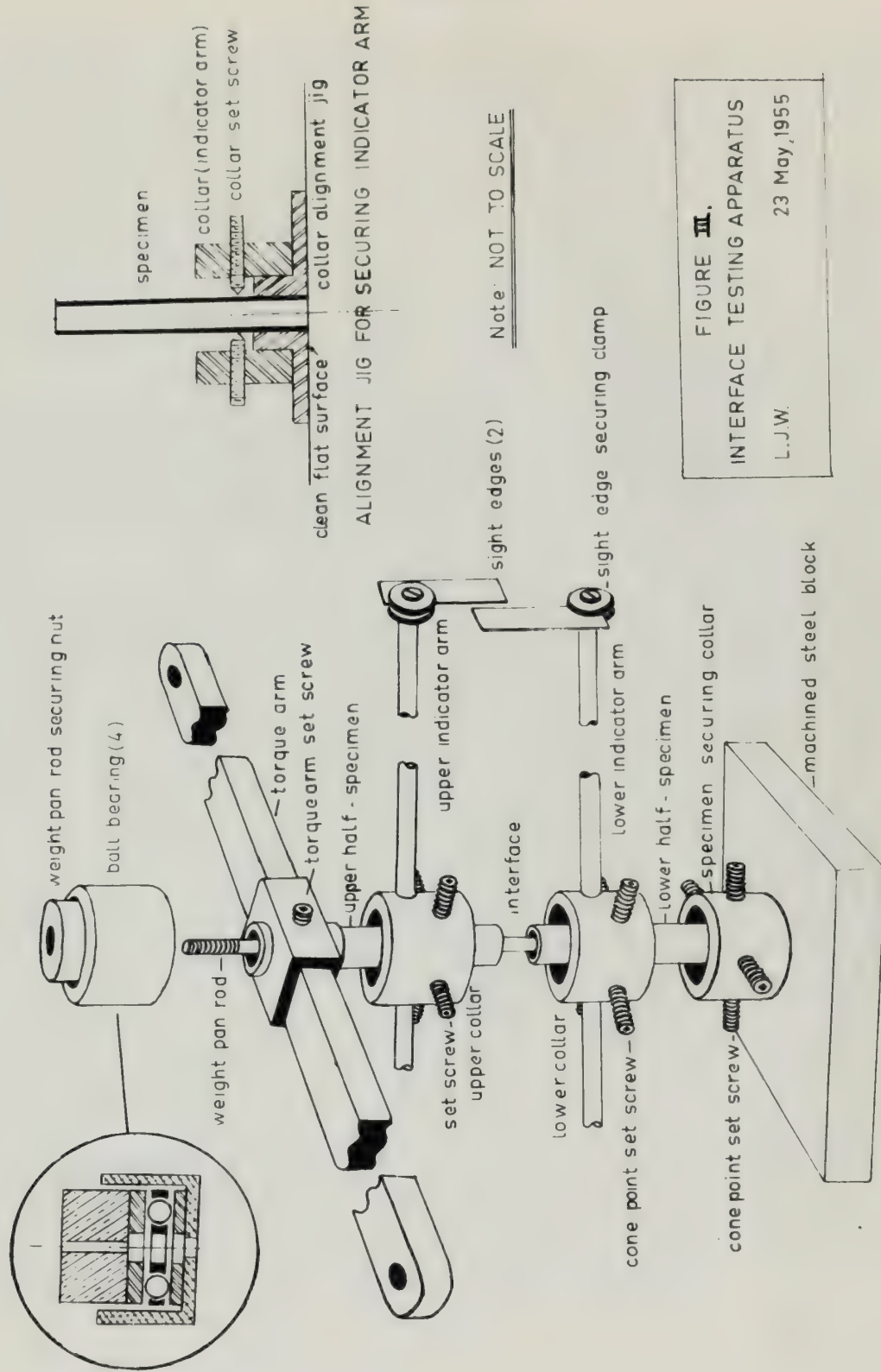


FIGURE III.  
INTERFACE TESTING APPARATUS

L.J.W.

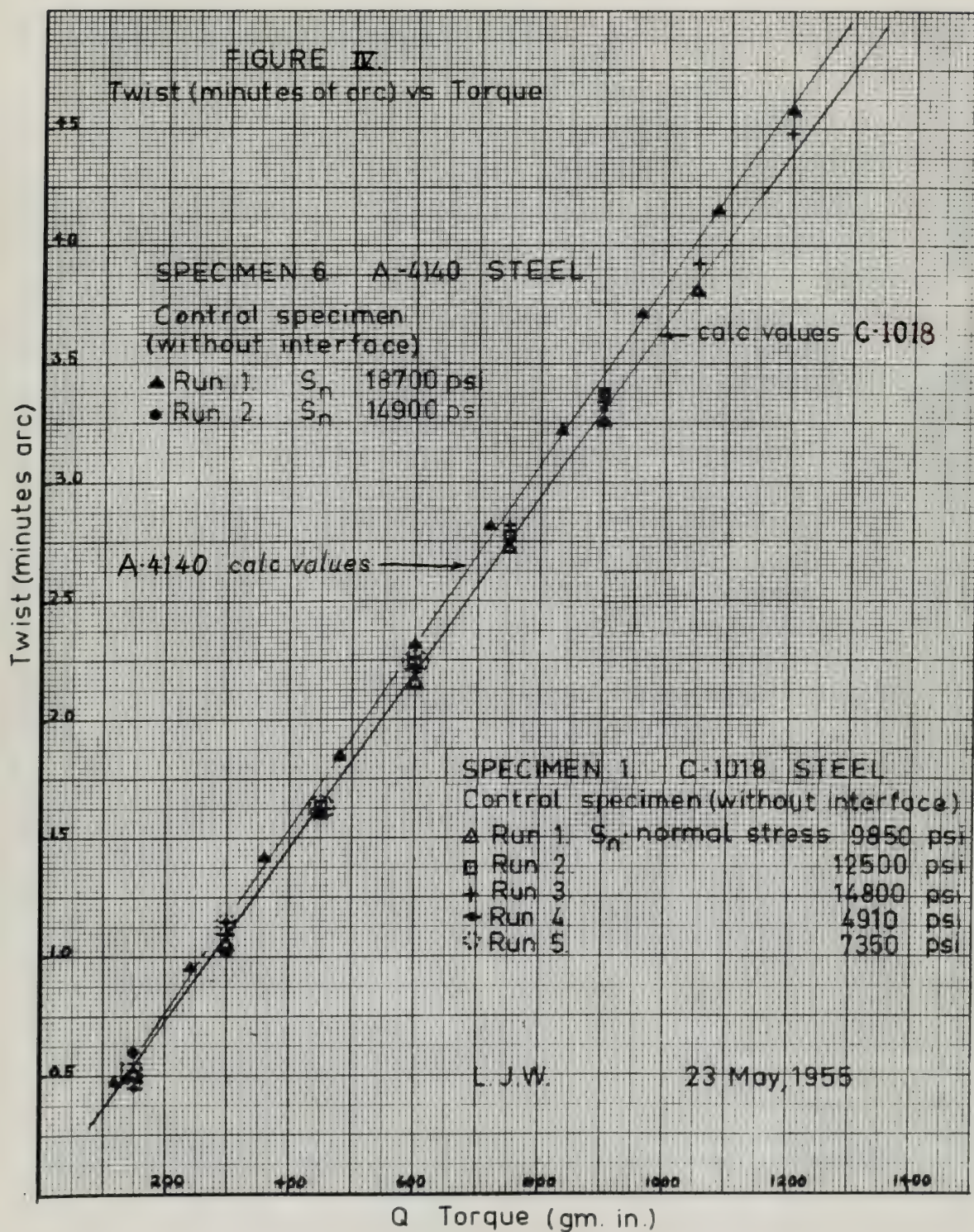
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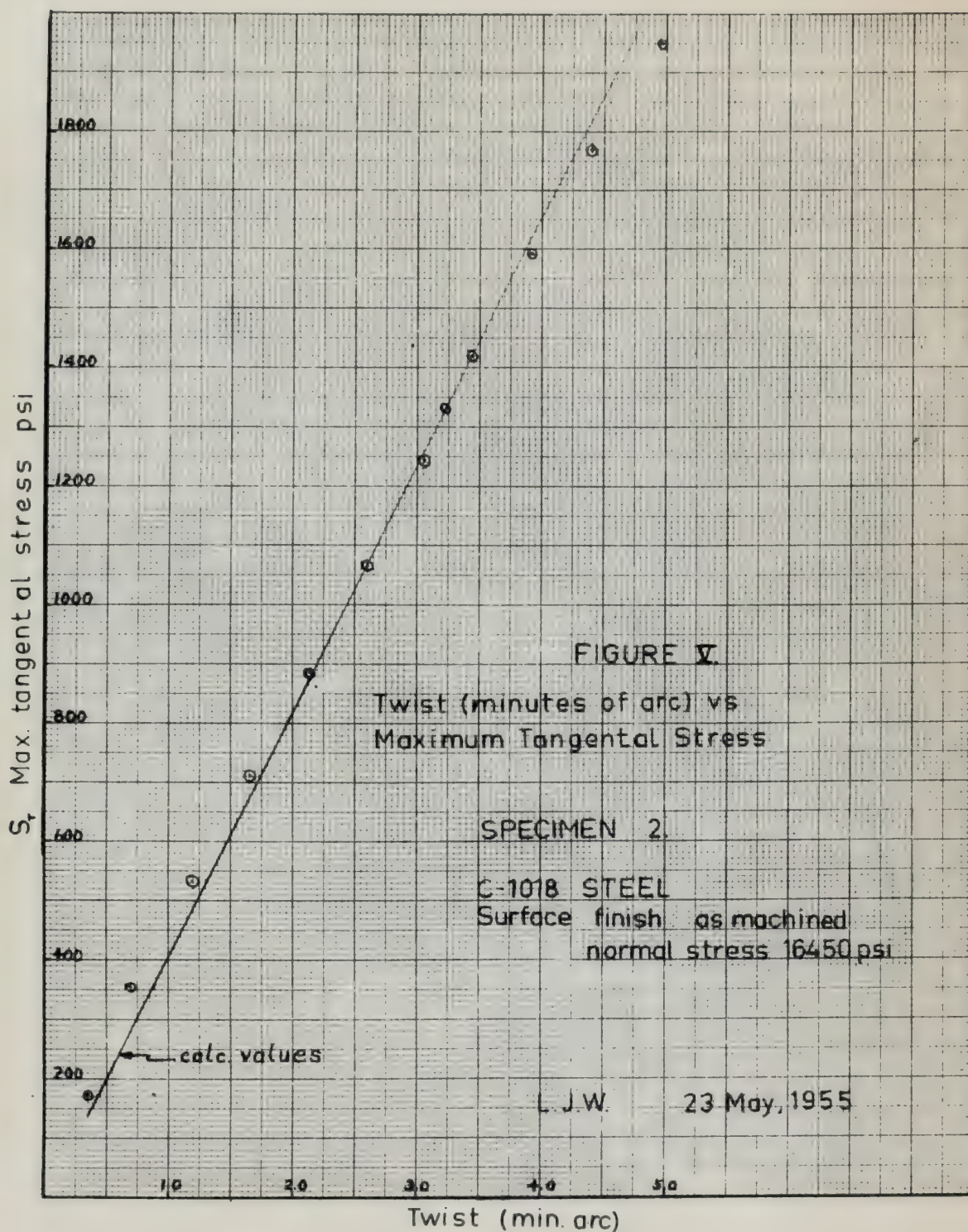
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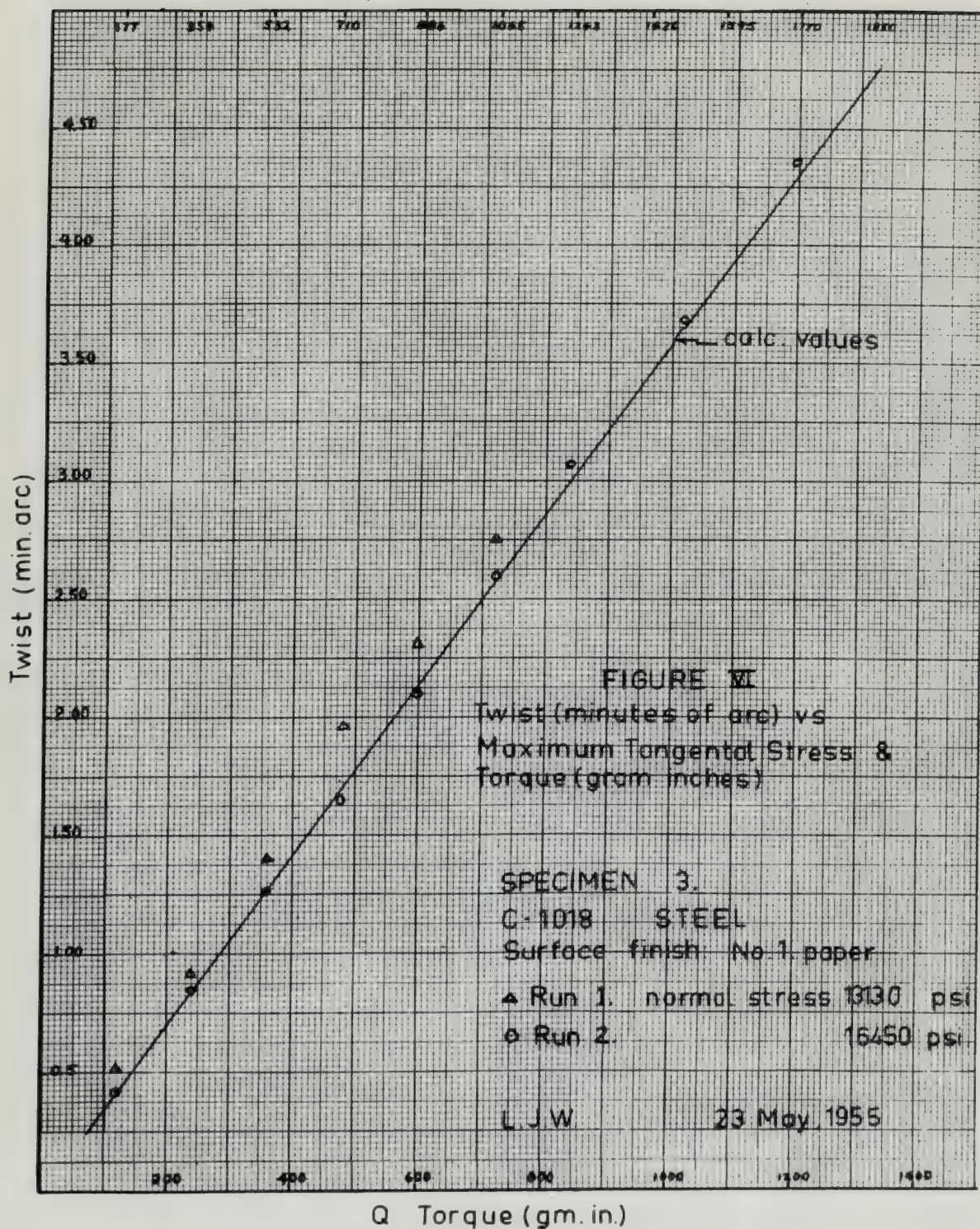








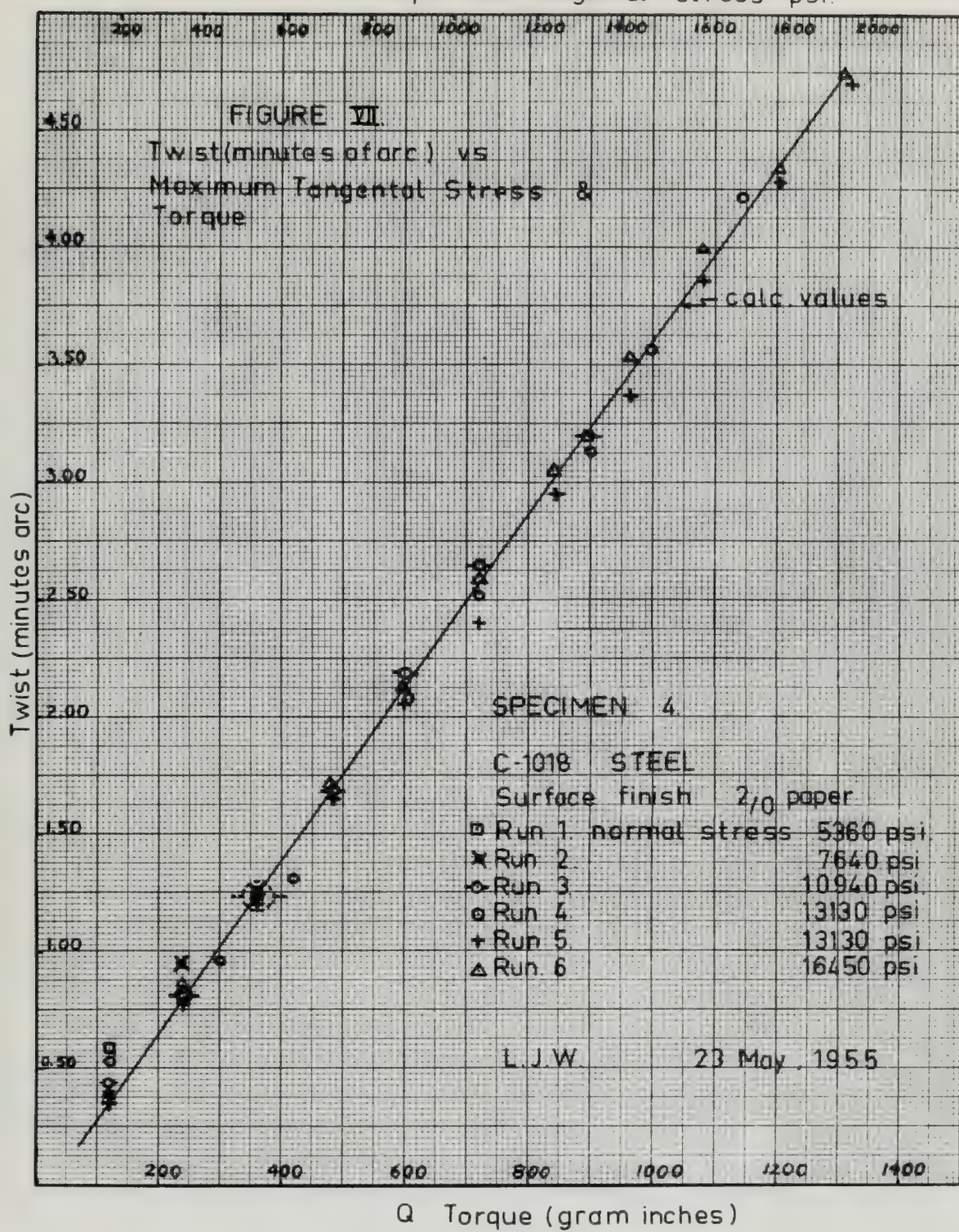


$S_T = \text{Max. tangential stress psi}$ 




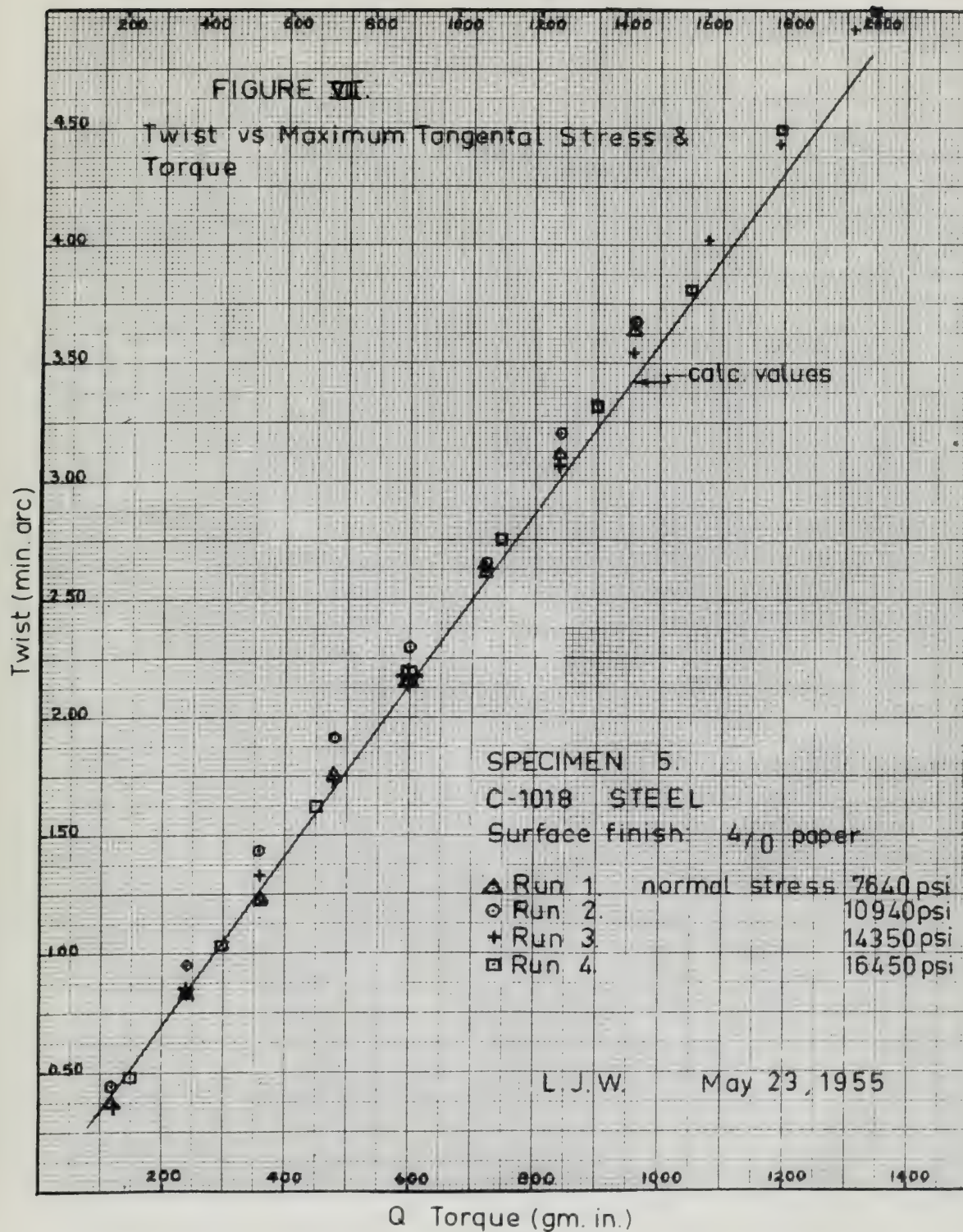


$S_T$  = Max. tangential stress psi







$S_r$  Max. tangential stress psi






$S_r$  = Max. tangential stress psi

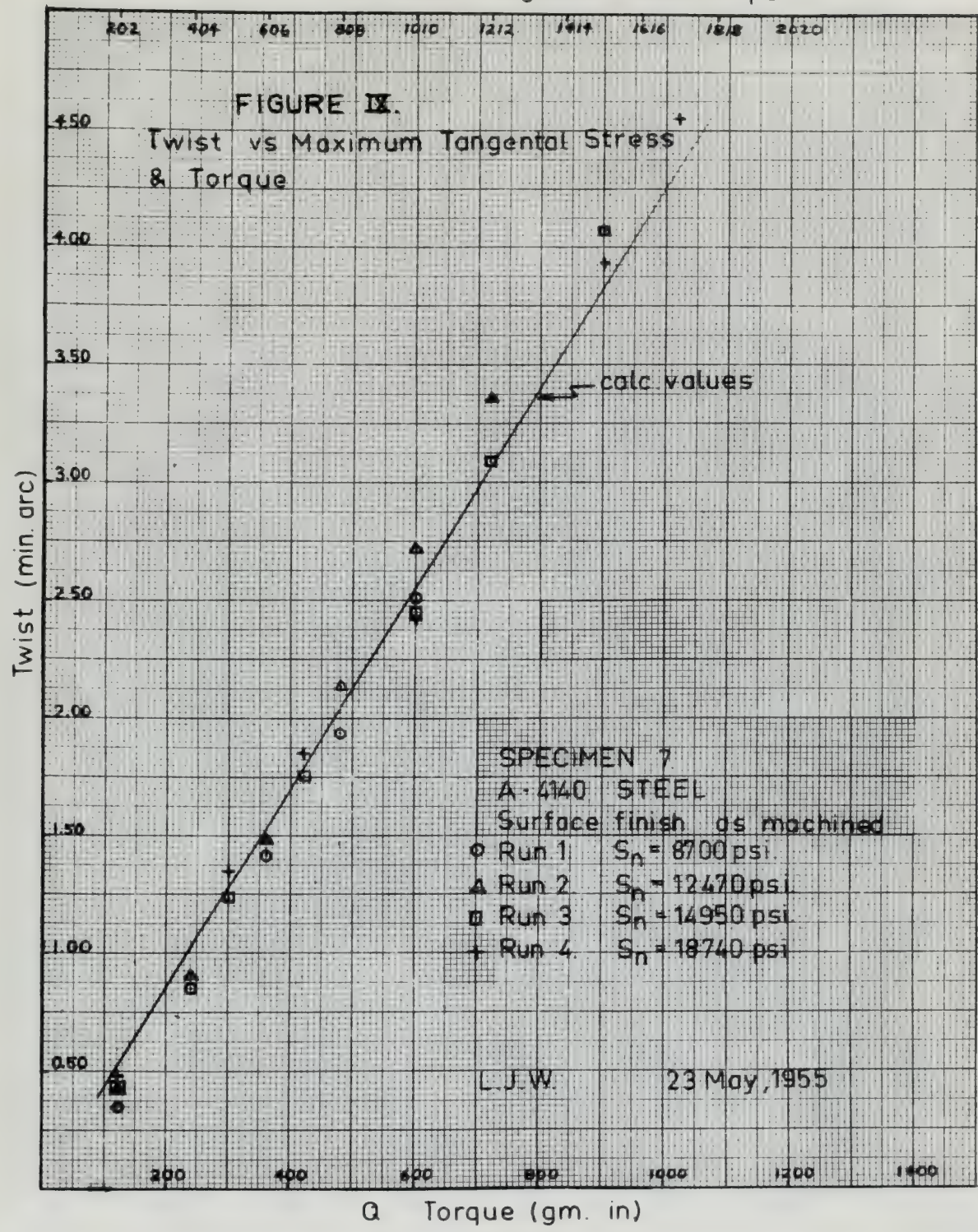






FIGURE 13.  
TWIST VS MAXIMUM TANGENTIAL STRESS

SPECIMEN 13.

Copper surface finish #1 paper

• Run 1  $S_n = 11170$  psi  
 ◊ Run 2. 13360 psi  
 Δ Run 3. 16700 psi

Twist (minutes-arc)

calc. values Copper

calc. values A-4140

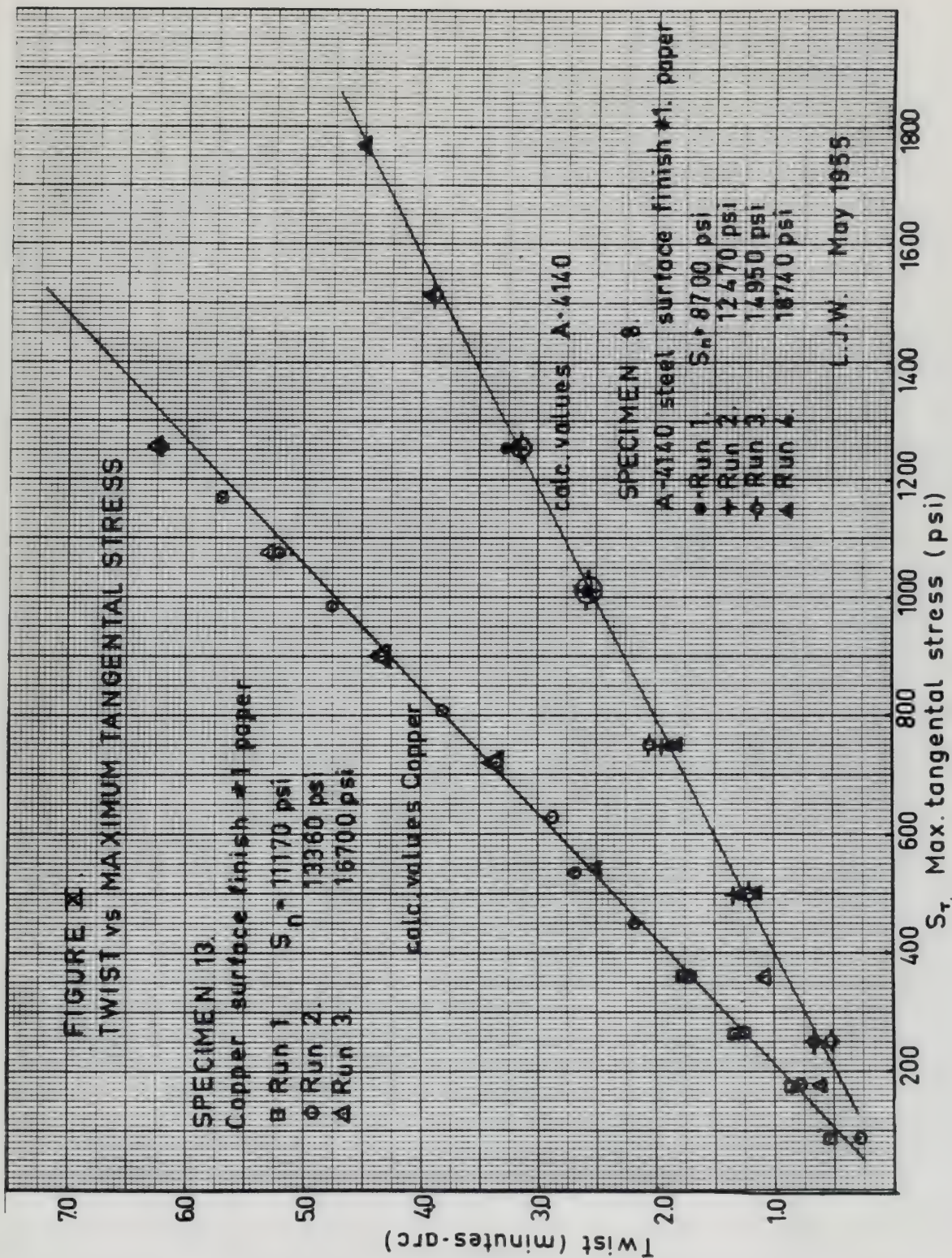
SPECIMEN 8.

A-4140 steel surface finish #1. paper

• Run 1.  $S_n = 8700$  psi  
 + Run 2. 12470 psi  
 ◊ Run 3. 14950 psi  
 Δ Run 4. 16740 psi

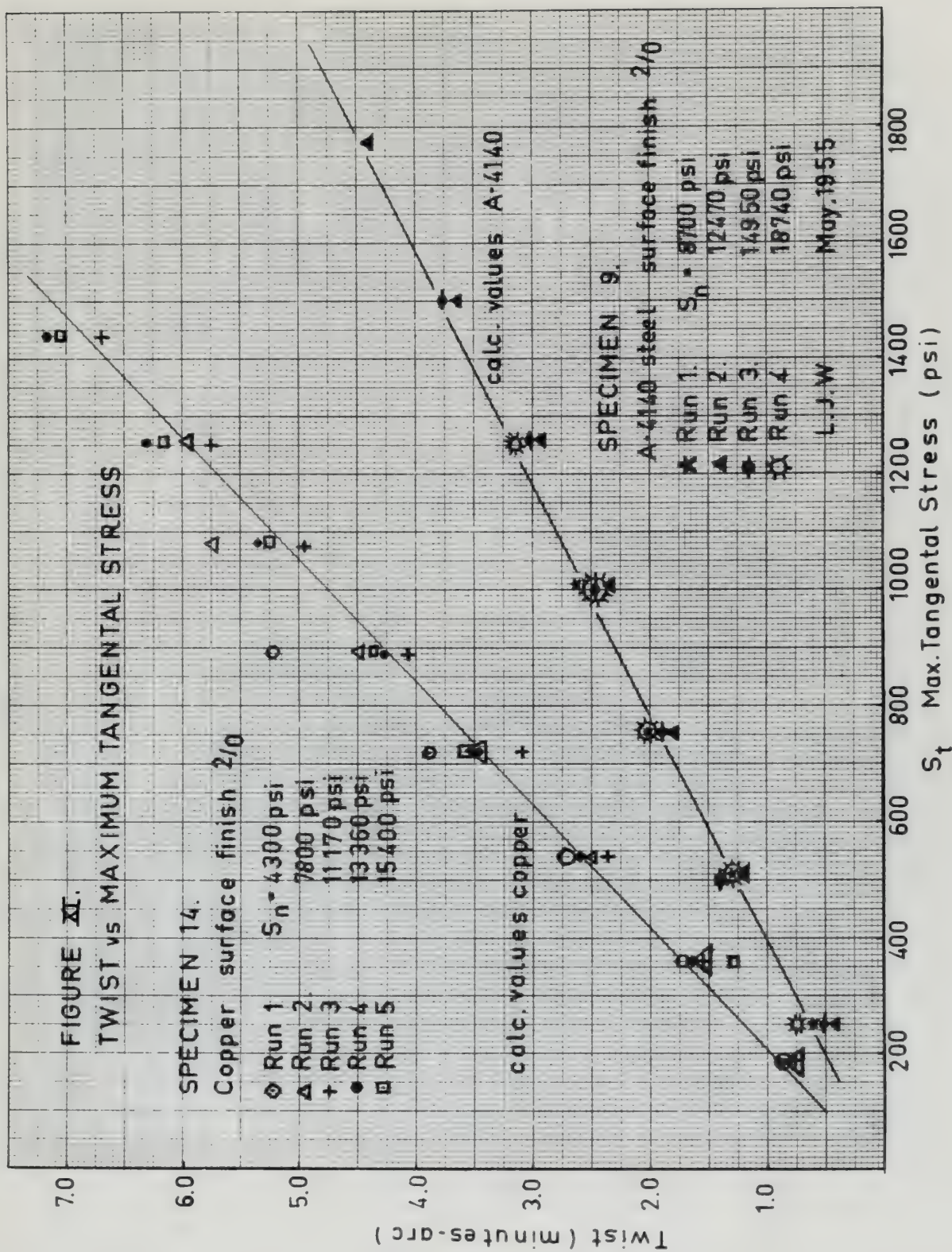
L.J.W. May 1955

$S_T$  Max. tangential stress (psi)



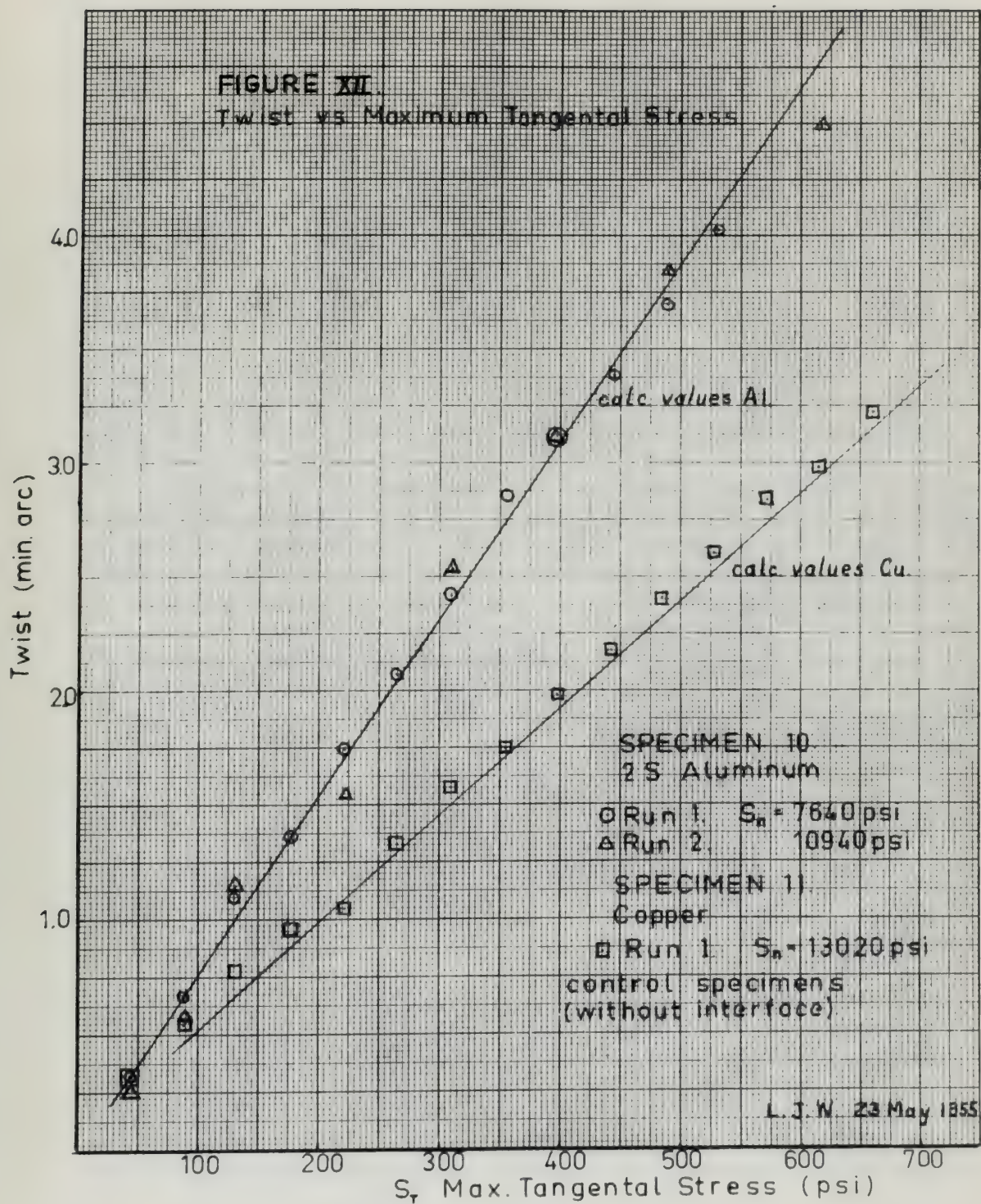
















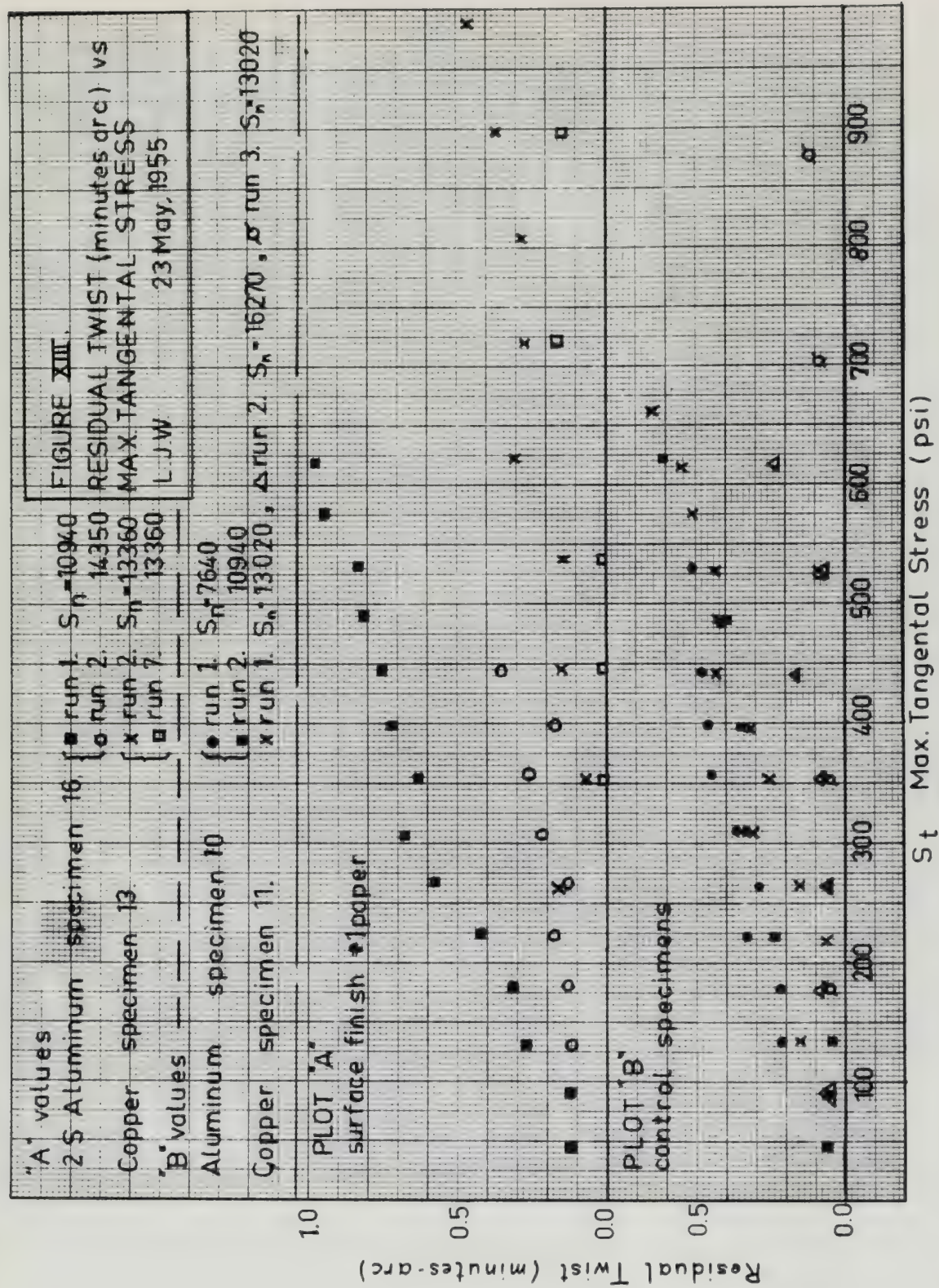






FIGURE XIV  
Maximum Tangential Stress vs  
Apparent Slip at Interface

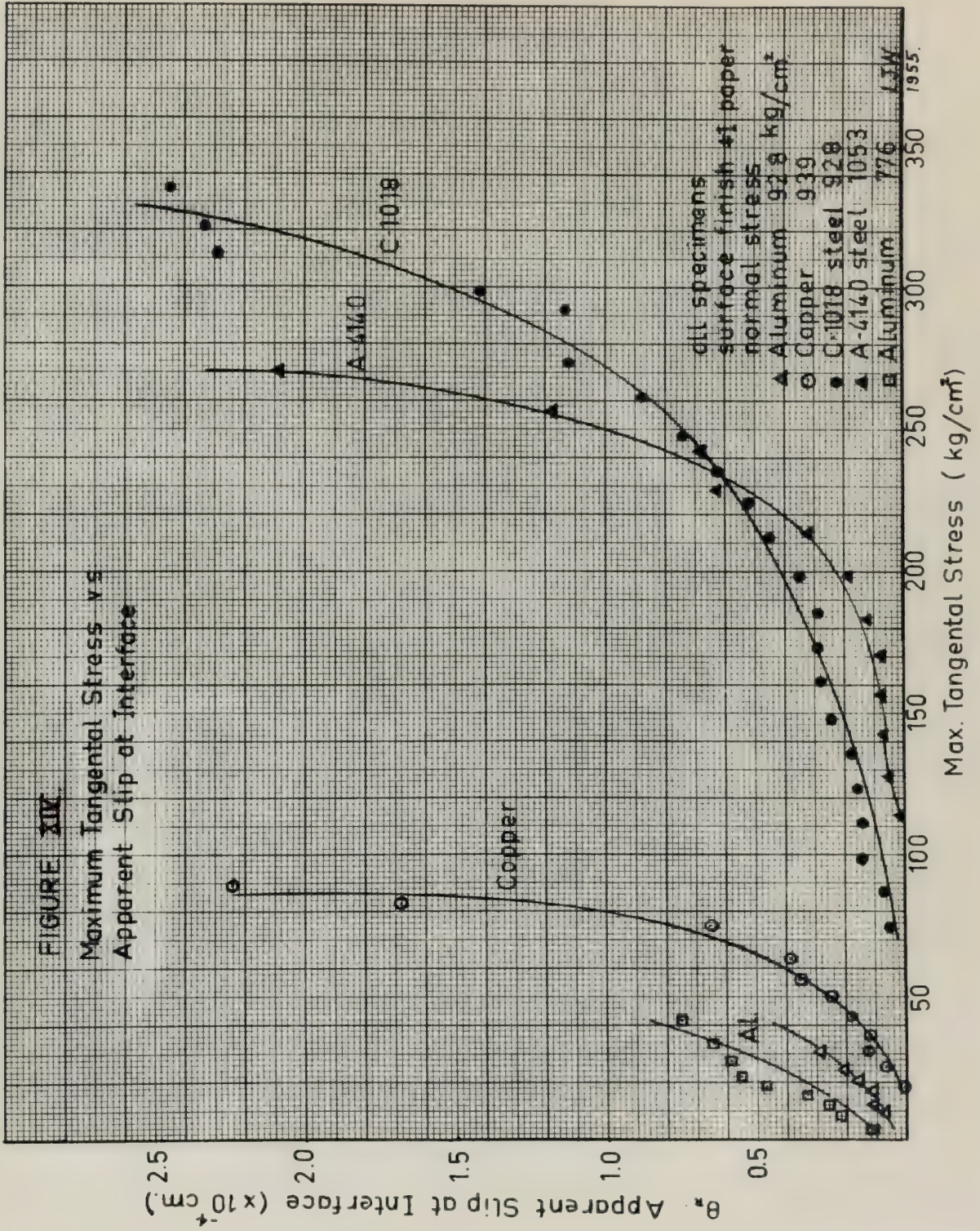
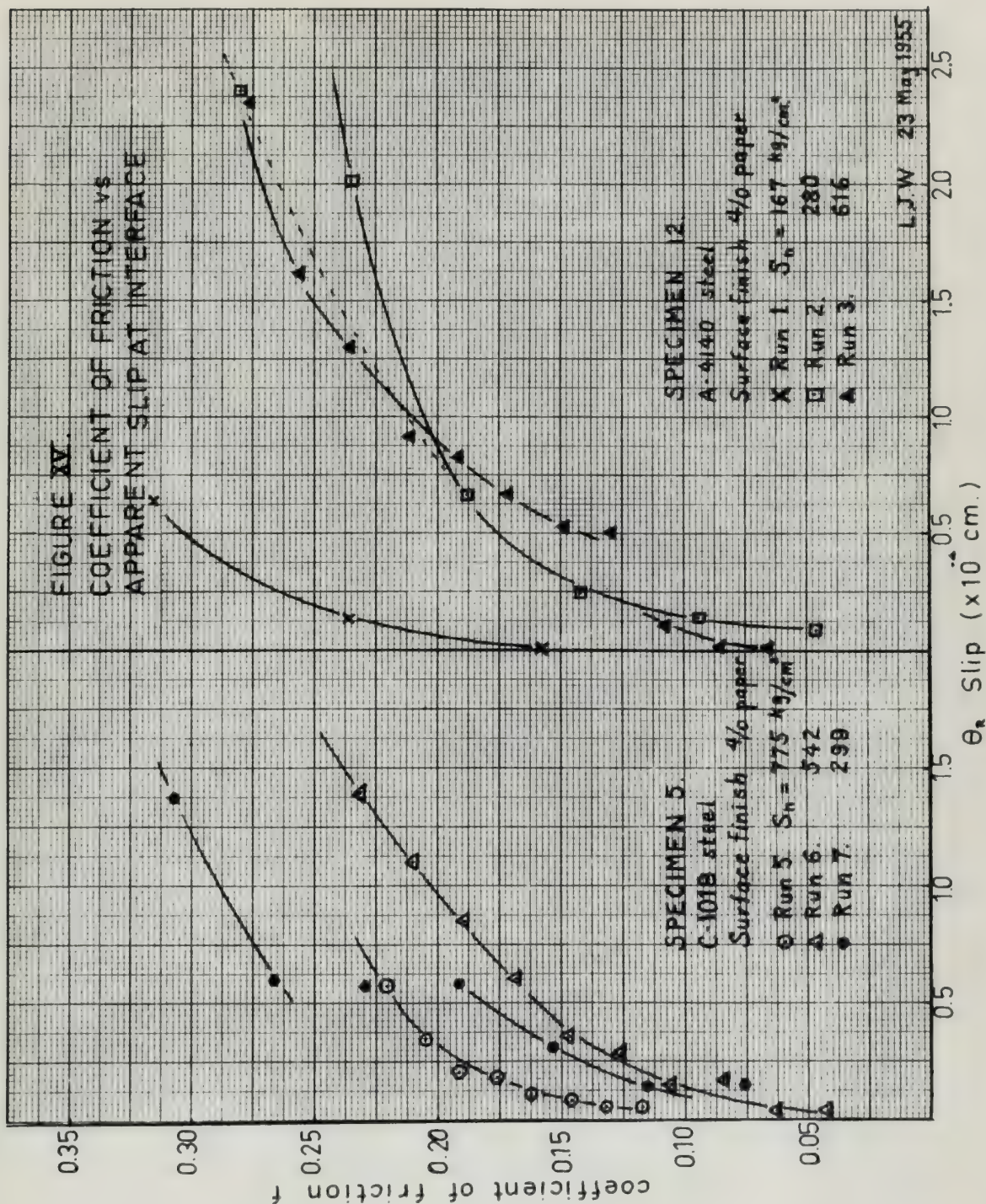






FIGURE XV.

COEFFICIENT OF FRICTION VS  
APPARENT SLIP AT INTERFACE







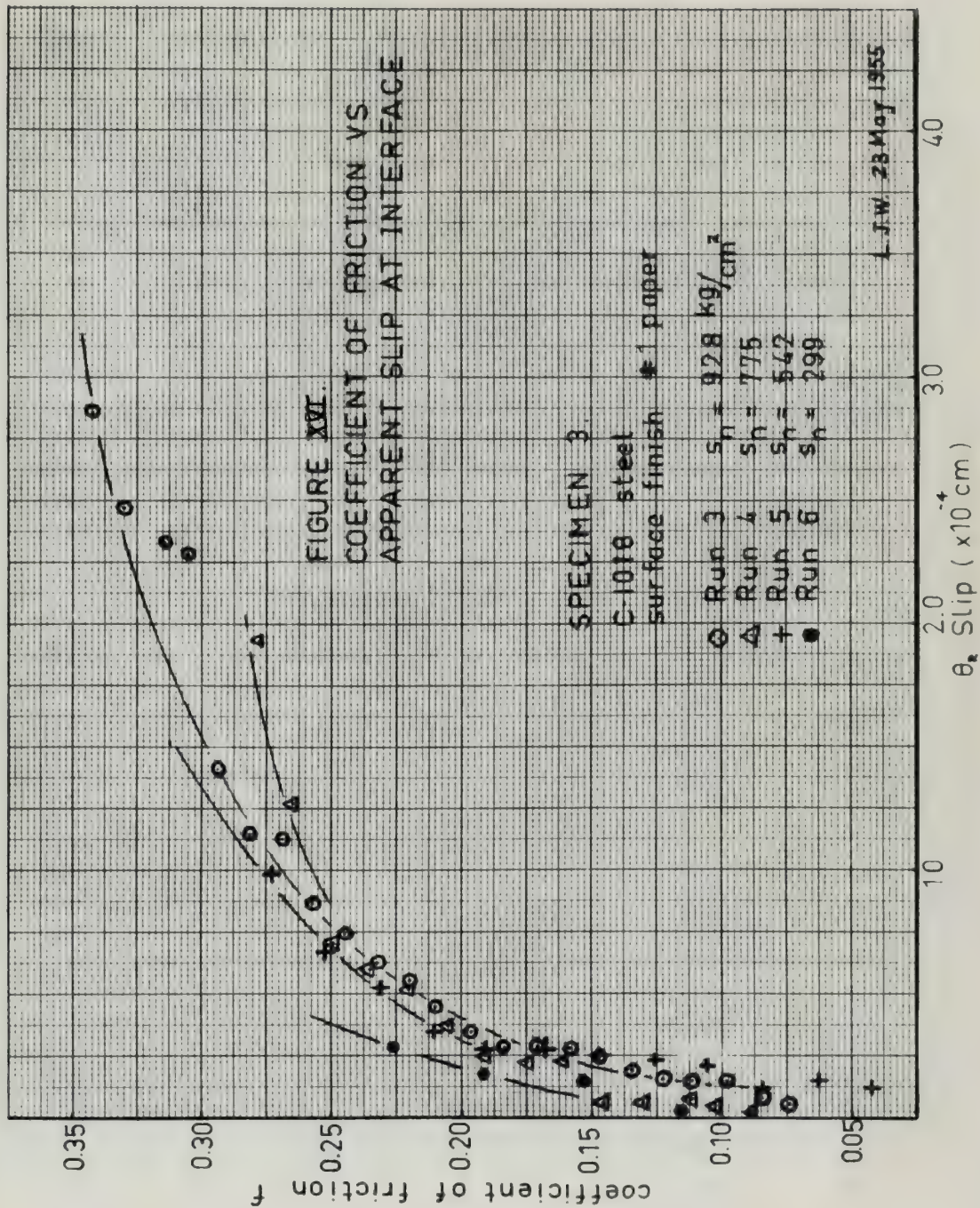






FIGURE XVII.

Coefficient of Friction vs  
Apparent Slip at Interface

0.3

coefficient of friction  $f$

0.2

SPECIMEN 8

A 4140 surface finish #1 paper

• Run 7  $S_n = 1053 \text{ kg/cm}^2$

▲ Run 8  $S_n = 883$

○ Run 9  $S_n = 616$

+ Run 10  $S_n = 340$

L.J.W. 23 May 1955

4.0

$\theta_R$  Slip ( $\times 10^4 \text{ cm.}$ )

1.0

2.0

3.0

$f = 0.155 \text{ at } 5.30 \text{ } f_{ac} +$





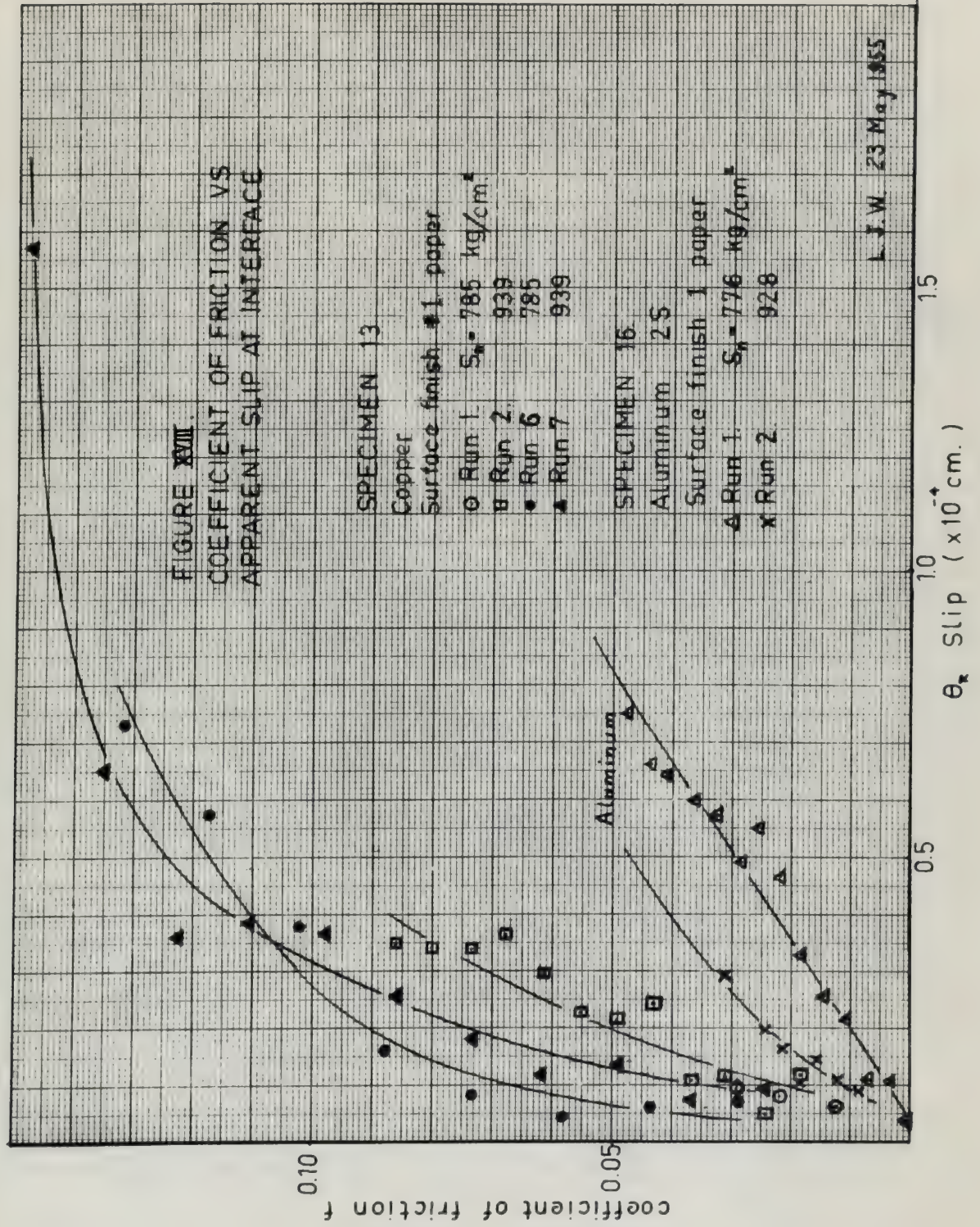
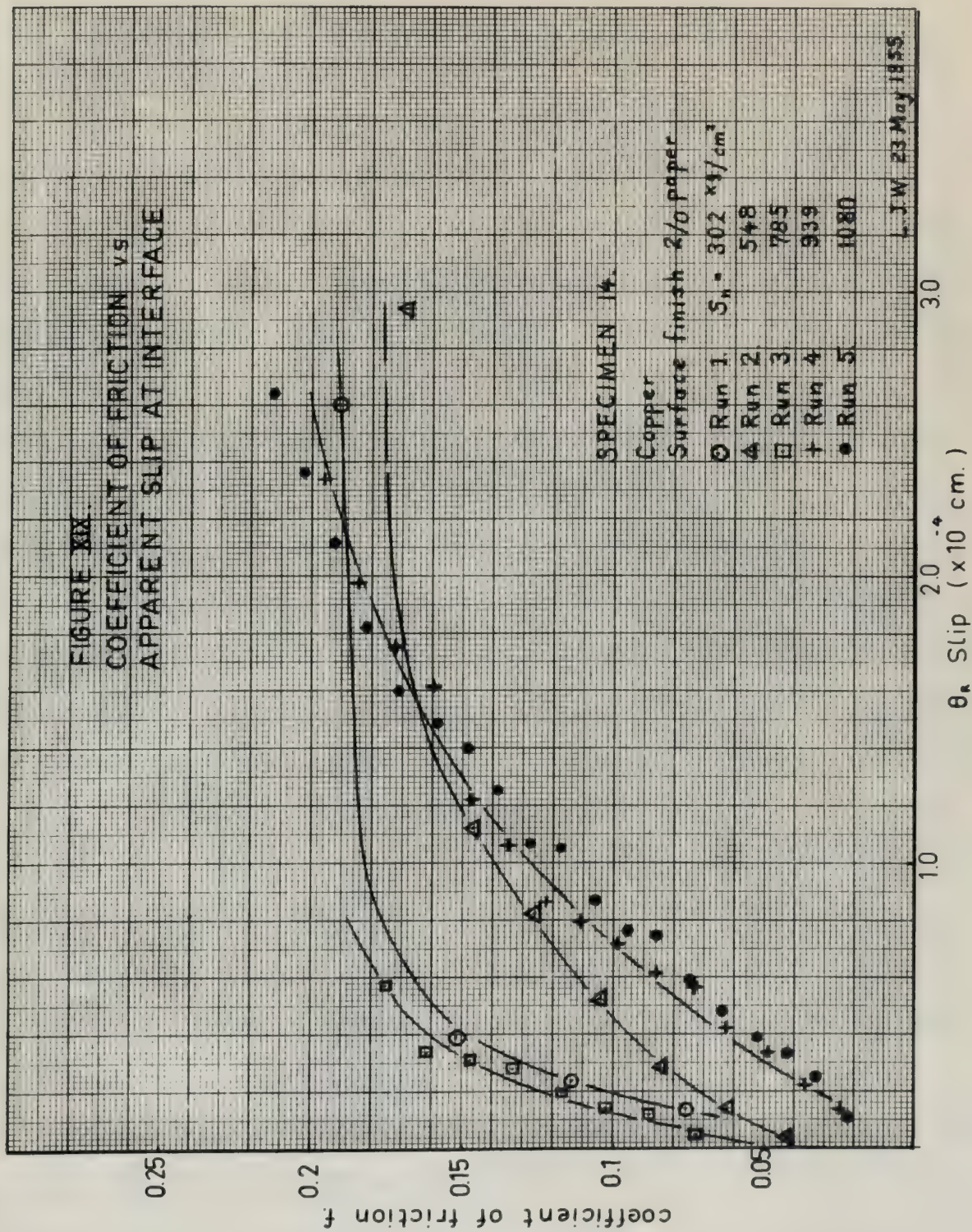






FIGURE XIX.  
COEFFICIENT OF FRICTION vs  
APPARENT SLIP AT INTERFACE







#### IV. DISCUSSION OF RESULTS

##### A. Initial Elastic Behavior of Metal Interfaces

Figures IV and XII compare observed deflections of the control specimens with computed deflections as predicted by elastic theory. All points plotted for the two steel control specimens are within the elastic range, as the test runs were terminated at the first indication of possible permanent deformation.

The values of shear modulus selected for the C-1018 and A-4140 steels were, respectively,  $12 \times 10^6$  and  $11.9 \times 10^6$  psi. Marks<sup>(6)</sup> gives the range of shear modulus values for all steels, excepting 18-8 stainless, as 11.0 to  $11.9 \times 10^6$  psi. The computed angle of twist varies inversely with the value of shear modulus. Therefore it can be seen that, with the values of shear modulus selected, the computed deflections will be the minimum expected. As the observed values of twist agree with the minimum computed values, the possibility of excessive elastic twist in the control specimen is eliminated.

The shear modulus values for copper (hard-drawn tough pitch) and 28 Aluminum were given in the Handbook as 6.0 and  $3.7 \times 10^6$  psi, respectively.

Figures V to VIII show the results of tests conducted with C-1018 steel specimens having various surface finishes and normal loads. Due to the close agreement between observed and





computed values of deflection for the control specimens, the observed angles of twist are compared with their corresponding theoretical value in this work.

The consistent agreement between test results for specimens with and without interfaces indicates that the interface has very little, if any, effect on the elastic twist.

All test runs with non-ferrous specimens were performed with the lower end of the specimen locked against movement. These test runs extended past the point at which the indicator failed to return to the initial position. The "B" plot of Figure XIII gives the observed values of residual twist recorded for the non-ferrous control specimen runs shown on Figure XII. Hard-drawn electrolytic tough pitch copper has a yield strength of 40,000 psi with 0.5% extension under load. Three successive runs on the copper control specimen show this effect clearly. The recorded values of deformation decreased with each run. Plot "A" of this figure shows the residual twist recorded for similar runs conducted on specimens with a No.1 surface finish. The effects contributed by the metal interface can easily be obtained by subtraction of the plotted values for any two corresponding tests. The point at which slip occurs on the copper specimen is easily noted, as the residual twist value increased sharply at that point.

Figures X and XI compare observed and calculated values of deflection for various test runs on copper and A-4140 steel specimens. These tests further substantiate the results recorded previously for C-1018 steel. Test runs using copper,

ing theoretical value in this work.



C-1018 steel, or A-4140 steel under various conditions of normal loading and with different degrees of surface finish failed to indicate any material contribution by the interface to elastic twist.

#### B. Initial Frictional Behavior of Metal Interfaces

Figure XIV compares the results of a similar test run conducted on four different metals. Comparing the results of the two steel specimens, it is seen that deformation occurred first in the C-1018 steel. This is attributed to yield in the asperities in the metal interface. C-1018 steel, with a yield strength of 48,000 psi as compared with 131,000 psi for the A-4140, would be expected to yield first. It should be noted that the deformation observed here is of the order of 0.000005 cm. The C-1018 curve crosses the A-4140 line at an apparent slip value of 0.000006 cm. This shows that sliding effects are now predominant, as the A-4140 steel with its smaller coefficient of friction slides more easily than the C-1018 steel.

Deformation in the two non-ferrous specimens commenced at fairly low values of tangential stress. It is interesting to note that the aluminum slid freely, and the copper curve rose sharply, at the same value of  $\theta_R$  at which the two steel curves crossed. Again it appears that, up to this point, deformation was primarily due to yield in the material, while subsequent failure of the interfacial bonds permitted friction effects to predominate.



Figures XV to XIX indicate that the value of the friction coefficient increases with small increments of slip until the normally expected value is attained, at which point the curve flattens out and free sliding results.

The curves plotted in Figures XVI, XVII, and XIX are all fairly smooth, giving no indication of a transition from interfacial deformation to true slip. The plots on Figures XV and XVIII, in contrast, show prominent breaks and discontinuities in the region below 0.00005 cm of apparent slip. The apparent slip in these cases may be due to slip, deformation of the metal, or combinations of both effects. An accurate evaluation of slip with this apparatus is therefore impossible due to the problem of separating the true slip from the deformations produced by yield effects in the asperities in the metal interfaces.

In evaluating these results, some information on the accuracy of the readings is in order. A discussion of the accuracy of the apparatus follows in Appendix A, Details of Procedure.

$$\theta_R = \pm 1.80 \times 10^{-7} \text{ centimeters}$$

$$\psi_0 = \pm 0.00229 \text{ minutes of arc}$$





## V. CONCLUSIONS AND RECOMMENDATIONS

### A. Conclusions - Elastic Behavior

1. The metal interface does not contribute materially to elastic twist.
2. Elastic deflections of a metal specimen with an interface agree with values computed by elastic theory for a continuous specimen.
3. The deflections predicted by elastic theory are obtained regardless of metal, surface finish, or normal stress selected. (Normal loads applied were selected so that resulting normal stresses were safely below critical range which would cause buckling or compressive failure of the column.)
4. The predicted elastic deflections are obtained in non-ferrous metals even though extension of the metal under load resulted in small concurrent permanent deformations.

### B. Conclusions - Frictional Behavior

1. The value of the coefficient of friction was initially low for extremely small values of slip at the interface.
2. The value of the coefficient increased with small increments of slip up to the normally expected value at which point free sliding resulted.

2. Theoretical Results

The theoretical results are now summarized briefly.

1. The value of the coefficient of friction was

initially low for extremely small values of slip

at the interface.

2. The value of the coefficient increased with small

increments of slip up to the normally expected

value at which point free sliding resulted.

column.)

3. The theoretical results are now summarized briefly.

The value of the coefficient of friction was

initially low for extremely small values of slip

at the interface.

B. Conclusions - Theoretical Results

1. The value of the coefficient of friction was

initially low for extremely small values of slip

at the interface.

2. The value of the coefficient increased with small

increments of slip up to the normally expected

value at which point free sliding resulted.



3. An exact assessment of the increments of slip at the interface was impossible with this experimental technique, due to small amounts of deformation contributed by yield in the asperities in the metal interface. Notwithstanding this factor, the trend indicated that the coefficient of friction starts from zero for zero values of slip and applied stress, and increases with small increments of slip until the normal value is reached.

#### C. Recommendations

Due to the consistency of the results, both quantitatively and qualitatively, further investigation of metal interfaces for abnormal elastic twist is not recommended.

This apparatus was not designed for investigation of frictional behavior in the slow speed range; therefore modifications of the equipment are deemed necessary prior to any further investigations of the stick slip phenomena with this basic experimental arrangement.

in most instances at the beginning of the  
of the interface was impossible with this exper-  
imental technique. As a result of this  
condition described in detail in the caption  
in the next interface. Notwithstanding this  
factor, the tests indicated that the coefficient  
of friction starts from zero for zero values of  
slip and applied stress, and increases with well  
increments of slip until the normal value is  
reached.

continued.

### 3. Experimental Results

Due to the complexity of the results, this section  
describes the results of the tests in a series of  
figures. The first figure is a plot of the  
coefficient of friction versus the applied stress.  
This figure was not included for reasons of  
space. It is also shown that the coefficient of  
friction of the system was not constant when in  
contact with the slip and the system with the  
slip was not constant.

APPENDIX A  
DETAILS OF PROCEDURE



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APPENDIX A

LIST OF REFERENCES

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## DETAILS OF PROCEDURE

In the redesign of the test apparatus, various schemes for measuring angular twist of the specimen were considered. Selection of an optical lever in lieu of the metal indicator arms of the original apparatus was rejected due to the length of light beam required. This would require excessive floor space for the apparatus or would involve the use of a complex prism system. Distribution of the equipment over a large floor space would present a problem in isolating the apparatus from vibrations imparted by the building structure. Another source of error would be encountered in the resolution of the light image on the measuring scale.

The possibility of utilizing interferometry was investigated. Measurement of exceedingly small angles of twist could be obtained by this means, but the cost and complexity of the apparatus required for this work were greater than warranted.

It was decided that a sufficient increase in the sensitivity of the system could be obtained by use of better materials, measuring equipment, and refinements in the experimental method.

The original apparatus utilized an apparatus having an indicator arm length of 7.5" and an optical vernier in which one scale unit represented 0.001 inch of indicator movement.

Estimating the movement of one indicator arm to  $\pm 0.1$  scale unit, the resulting accuracy with two arms would be  $\pm 0.2$  scale unit.





$$\psi_o = \frac{\psi}{R} \times \frac{180}{\pi} \times 60 = \text{observed twist in minutes of arc.}$$

Therefore accuracy of the original apparatus was

$$\psi_o = \pm \frac{0.0002}{7.5} \times 3440 = \pm 0.092 \text{ minutes of arc.}$$

By the use of a microscope equipped with a 10 x objective and an optical micrometer, the accuracy was increased considerably. The use of the light-weight but rigid tubular indicator arms permitted increasing the value of R to 12.328".

Calibration of the optical micrometer against a micrometer stage showed that one micrometer drum unit represented 0.00004101 inch of indicator movement. Estimating the micrometer readings to  $\pm 0.1$  drum unit would result in an accuracy in observed deflections of  $\pm 0.2$  drum units. Therefore, accuracy of the present apparatus is

$$\psi_o = \pm \frac{0.000008202}{12.33} \times 3440 = \pm 0.002290 \text{ minutes of arc}$$

The value of apparent slip ( $\theta_R$ ) measured with this apparatus is computed as follows: For the C-1018 steel specimen with the outside diameter of 0.2365" and inside diameter of 0.191", the mean radius ( $r_m$ ) of the specimen is 0.1069".

Therefore

$$\frac{\theta_R}{r_m} = \pm \frac{0.000008202}{12.33}$$

$$\theta_R = \pm 7.10 \times 10^{-6} \text{ inches}$$

$$\theta_R = \pm 1.80 \times 10^{-7} \text{ centimeters}$$

$$f(x) = \frac{1}{2} \left( \frac{1}{x} + \frac{1}{x^2} \right) = \frac{1}{2} \left( \frac{x+1}{x^2} \right)$$

THESE RESULTS WERE OBTAINED BY THE FOLLOWING PROCEDURE:

1. The first part of the document is a list of names and dates, which appears to be a record of some kind. The names are written in a cursive script, and the dates are in a more formal, printed style. The list is organized into two columns, with names on the left and dates on the right.

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ALL INFORMATION CONTAINED HEREIN IS UNCLASSIFIED EXCEPT WHERE SHOWN OTHERWISE

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## APPENDIX B

## SUMMARY OF DATA AND CALCULATIONS



# ARTICLE

## PROHIBITION OF THE SALE OF SUGARS

# ARTICLE

## SPECIMEN NO.1

Material: C-1018 Steel

Control Specimen:  
(without interface)

$$D_o = 0.2365''$$

$$D_1 = 0.191''$$

$$L = 1.0156''$$

$$D_o^2 - D_1^2 = 0.01945$$

$$D_o^4 - D_1^4 = 0.001798$$

$$A = \frac{E(D_o^2 - D_1^2)}{4} = 0.01526$$

$$S_N = \frac{F_N}{A} = \frac{F_N}{0.01526} \text{ psi}$$

$$S_T = 1.121 \times 10^{-2} \frac{D_o}{D_o^4 - D_1^4} \times Q_A$$

$$S_T = 1.475 \times Q_A \text{ psi}$$

$$\psi_c = \frac{77.3 \times L \times Q_A}{(D_o^4 - D_1^4) \times E_s}$$

$$E_s = 12 \times 10^6 \text{ psi}$$

$$\psi_c = 0.00364 Q_A \text{ min.arc.}$$

$$\psi_o = 0.01144 \psi_s \text{ min.arc.}$$

Run No.1

$$F_N = 150 \text{ lb.}$$

$$S_N = 9850 \text{ psi}$$

 $\psi_o$ 

0.504

1.053

1.590

2.165

2.735

3.265

3.800

--

 $\psi_c$ 

0.547

1.093

1.640

2.185

2.733

3.280

3.830

4.370

 $S_T$ 

221.5

443

665

886

1107

1330

1550

1770

 $Q_A$ 

150

300

450

600

750

900

1050

1200

Run No.2

$$F_N = 190.7 \text{ lb.}$$

$$S_N = 12500 \text{ psi}$$

 $\psi_o$ 

0.504

1.018

1.635

2.250

2.776

3.380

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SPECIMEN NO.1 (continued)

		<u>Run No.3</u>	<u>Run No.4</u>	<u>Run No.5</u>
		$F_N = 225.4 \text{ lb.}$	$F_N = 74.91 \text{ lb.}$	$F_N = 111.9 \text{ lb.}$
		$S_N = 14800 \text{ psi}$	$S_N = 4910 \text{ psi}$	$S_N = 7350 \text{ psi}$
$Q_A$	$S_T$	$\psi_c$	$\psi_o$	$\psi_o$
150	221.5	0.547	0.457	0.515
300	443	1.093	1.155	1.109
450	665	1.640	- -	1.647
600	886	2.185	- -	2.240
750	1107	2.733		
900	1330	3.280		
1050	1550	3.830		
1200	1770	4.370		



Specimen No.2

Material: C-1018 Steel

Surface Finish:  
As Machined (Lathe)Specimen No.3

Material: C-1018 Steel

Surface Finish:  
No.1 Emery Paper

$$D_o = 0.2365''$$

$$D_1 = 0.191''$$

$$L = 1.0078''$$

$$D_o^2 - D_1^2 = 0.01945$$

$$D_o^4 - D_1^4 = 0.001798$$

$$A = \frac{\pi}{4} (D_o^2 - D_1^2) = 0.01526 \text{ in}^2$$

$$S_N = \frac{F_N}{A} = \frac{F_N}{0.01526} \text{ psi}$$

$$S_T = 1.121 \times 10^{-2} \frac{D_o}{D_o^4 - D_1^4} \times Q_A$$

$$S_T = 1.475 \times Q_A \text{ psi}$$

$$\psi_c = \frac{77.3 \times L \times Q_A}{(D_o^4 - D_1^4) \times E_s}$$

$$\psi_c = 0.00362 Q_A \text{ min. arc.}$$

$$\psi_o = 0.01144 \psi_s \text{ min. arc.}$$

SPECIMEN NO.2SPECIMEN NO.3Run No.1

$$F_N = 251.2 \text{ lb.}$$

$$S_N = 16450 \text{ psi}$$

$$\psi_o$$

$$\psi_c$$

$$S_T$$

$$Q_A$$

$$0.355$$

$$0.435$$

$$177$$

$$120$$

$$0.687$$

$$0.8695$$

$$354$$

$$240$$

$$1.180$$

$$1.304$$

$$532$$

$$360$$

$$1.662$$

$$1.740$$

$$710$$

$$480$$

$$2.145$$

$$2.177$$

$$886$$

$$600$$

$$2.600$$

$$2.608$$

$$1065$$

$$720$$

$$3.050$$

$$3.043$$

$$1243$$

$$840$$

$$3.234$$

$$3.260$$

$$1330$$

$$900$$

$$3.440$$

$$3.480$$

$$1420$$

$$960$$

$$3.920$$

$$3.910$$

$$1595$$

$$1080$$

$$4.400$$

$$4.350$$

$$1770$$

$$1200$$

$$4.970$$

$$4.780$$

$$1950$$

$$1320$$

Run No.1

$$F_N = 200.3 \text{ lb.}$$

$$S_N = 13130 \text{ psi}$$

$$\psi_o$$

$$\psi_c$$

$$S_T$$

$$Q_A$$

$$0.435$$

$$0.435$$

$$177$$

$$120$$

$$0.918$$

$$0.8695$$

$$354$$

$$240$$

$$1.410$$

$$1.304$$

$$532$$

$$360$$

$$1.925$$

$$1.740$$

$$710$$

$$480$$

$$2.315$$

$$2.177$$

$$886$$

$$600$$

$$2.760$$

$$2.608$$

$$1065$$

$$720$$

$$3.074$$

$$3.043$$

$$1243$$

$$840$$

$$3.234$$

$$3.260$$

$$1330$$

$$900$$

$$3.440$$

$$3.480$$

$$1420$$

$$960$$

$$3.920$$

$$3.910$$

$$1595$$

$$1080$$

$$4.400$$

$$4.350$$

$$1770$$

$$1200$$

$$4.970$$

$$4.780$$

$$1950$$

$$1320$$

Run No.2

$$F_N = 251.2 \text{ lb.}$$

$$S_N = 16450 \text{ psi}$$

$$\psi_o$$

$$\psi_c$$

$$S_T$$

$$Q_A$$

$$0.413$$

$$0.435$$

$$177$$

$$120$$

$$0.849$$

$$0.8695$$

$$354$$

$$240$$

$$1.260$$

$$1.304$$

$$532$$

$$360$$

$$1.650$$

$$1.740$$

$$710$$

$$480$$

$$2.100$$

$$2.177$$

$$886$$

$$600$$

$$2.590$$

$$2.608$$

$$1065$$

$$720$$

$$3.074$$

$$3.043$$

$$1243$$

$$840$$

$$3.234$$

$$3.260$$

$$1330$$

$$900$$

$$3.440$$

$$3.480$$

$$1420$$

$$960$$

$$3.920$$

$$3.910$$

$$1595$$

$$1080$$

$$4.400$$

$$4.350$$

$$1770$$

$$1200$$

$$4.970$$

$$4.780$$

$$1950$$

$$1320$$



[illegible]
$$A^0 = 0.0035 \text{ } ^\circ \text{C}^{-1}$$
$$V^0 = \frac{(V_0^0 - V_0^2) \times V^2}{(V_0^0 - V_0^2) + V^2}$$
$$\log_e x = 2.74.1 = 7.2$$
$$2.01 \times 10^{-1} = 7.2$$
$$s = \frac{v}{f} = \frac{0.0120}{1} = 0.0120 \text{ m}$$
$$T = \frac{1}{2} \left( \frac{1}{\mu_1} + \frac{1}{\mu_2} \right) = \frac{1}{2} \left( \frac{1}{\mu_1} + \frac{1}{\mu_2} \right) = \frac{1}{2} \left( \frac{1}{\mu_1} + \frac{1}{\mu_2} \right)$$
$$\frac{1}{2} \frac{d}{dt} \left( \frac{1}{2} \frac{d}{dt} \right)$$
$$\theta_{22}^0 = \theta_{21}^0 = 0.016667$$

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## SPECIMEN NO. 3

Run No. 3 $F_N = 201.29 \text{ lb.}$  $F_N = 41.3 \text{ kg}$  $S_N = 13200 \text{ psi}$  $s_n = 928 \text{ kg/cm}^2$ 

$Q_A$	$s_t$	$\psi_R$	$\theta_R$	$f$	$Q_A$	$s_t$	$\psi_R$	$\theta_R$	$f$
240	24.9	- - -	- - -	0.0245	1920	199.0	0.459	$36.20 \times 10^{-6}$	0.1960
360	37.4	- - -	- - -	0.0368	2040	211.5	0.573	"	0.2083
480	49.9	- - -	- - -	0.0490	2160	224.0	0.641	"	0.2206
600	62.3	- - -	- - -	0.0613	2280	236.5	0.802	"	0.2326
720	74.9	0.057	$4.50 \times 10^{-6}$	0.0736	2400	248.7	0.940	"	0.2450
840	87.5	0.080	6.31	0.0859	2520	261.2	1.110	"	0.2575
960	99.9	0.195	15.38	0.0982	2640	273.5	1.420	"	0.2695
1080	112.0	0.183	14.42	0.1103	2760	293.0	1.432	"	0.2820
1200	124.3	0.206	16.25	0.1225	2880	298.5	1.787	"	0.2940
1320	137.0	0.229	18.06	0.1350	3000	311.0	2.910	"	0.3065
1440	149.4	0.321	25.30	0.1470	3120	323.0	2.945	"	0.3186
1560	161.6	0.344	27.12	0.1593	3240	336.0	3.095	"	0.3310
1680	174.3	0.355	28.00	0.1715	3360	348.5	3.660	"	0.3432
1800	186.6	0.344	27.12	0.1840	3480	361.0	- - -	- - -	0.3560





## SPECIMEN NO.3 (continued)

Run No.4

$$F_N = 168.16 \text{ lb.}$$

$$F_N = 76.4 \text{ kg}$$

$$S_N = 11020 \text{ psi}$$

$$s_n = 775 \text{ kg/cm}^2$$

$Q_A$	$\psi_R$	$\theta_R$	$f$
240	- - -	- - -	0.0293
360	- - -	- - -	0.0440
480	- - -	- - -	0.0587
600	- - -	- - -	0.0734
720	0.023	$1.81 \times 10^{-6}$	0.0880
840	0.057	4.50 "	0.1026
960	0.092	7.25 "	0.1172
1080	0.080	6.31 "	0.1320
1200	0.080	6.31 "	0.1466
1320	0.344	27.12 "	0.1613
1440	0.344	27.12 "	0.1760
1560	0.321	25.30 "	0.1906
1680	0.470	37.08 "	0.2050
1800	0.665	52.45 "	0.2200
1920	0.768	60.60 "	0.2345
2040	0.894	70.50 "	0.2492
2160	1.625	128.0 "	0.2640
2280	2.450	193.2 "	0.2785
2400	- - -	- - -	0.2935

TABLE 1

Logarithmic Regression

Logarithmic Regression

Logarithmic Regression

Logarithmic Regression

Logarithmic Regression

Logarithmic Regression

Logarithmic Regression

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Logarithmic Regression

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Logarithmic Regression

Logarithmic Regression

Logarithmic Regression

1900-1910

1911-1920

1921-1930

1931-1940

1941-1950

1951-1960

1961-1970

1971-1980

1981-1990

1991-2000

2001-2010

2011-2020

2021-2030

2031-2040

2041-2050

2051-2060

2061-2070

2071-2080

2081-2090

2091-2100

2101-2110

2111-2120

2121-2130

1900-1910

1911-1920

1921-1930

1931-1940

1941-1950

1951-1960

1961-1970

1971-1980

1981-1990

1991-2000

2001-2010

2011-2020

2021-2030

2031-2040

2041-2050

2051-2060

2061-2070

2071-2080

2081-2090

2091-2100

2101-2110

2111-2120

2121-2130

## SPECIMEN NO.3 (continued)

## Run No.5

 $P_N = 117.41 \text{ lb.}$  $P_N = 53.3 \text{ kg}$  $S_N = 7700 \text{ psi}$  $\sigma_N = 542 \text{ kg/cm}^2$ 

$Q_A$	$\psi_R$	$\theta_R$	$f$
240	0.172	$13.56 \times 10^{-6}$	0.042
360	0.183	"	0.063
480	0.149	"	0.084
600	0.275	"	0.105
720	0.218	"	0.126
840	0.321	"	0.147
960	0.332	"	0.168
1080	0.332	"	0.189
1200	0.470	"	0.210
1320	0.665	"	0.231
1440	0.860	"	0.252
1560	1.250	"	0.273
1680	- - -	- - -	0.294

## Run No.6

 $P_N = 64.8 \text{ lb.}$  $P_N = 29.4 \text{ kg}$  $S_N = 4250 \text{ psi}$  $\sigma_N = 299 \text{ kg/cm}^2$ 

$Q_A$	$\psi_R$	$\theta_R$	$f$
240	- - -	- - -	0.0762
360	0.057	$4.50 \times 10^{-6}$	0.1144
480	0.183	"	0.1522
600	0.218	"	0.1905
720	3.630	"	0.2280
840	- - -	- - -	0.2660



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SPECIMEN NO. 4

Material: C-1018 Steel

Surface Finish:  
2/0 paper

$$D_o = 0.2365"$$

$$D_i = 0.191"$$

$$L = 1.0078"$$

$$D_o^2 - D_i^2 = 0.01945$$

$$D_o^4 - D_i^4 = 0.001798$$

$$A = \frac{\pi}{4} (D_o^2 - D_i^2) = 0.01526 \text{ in}^2$$

$$S_N = \frac{F_N}{0.01526} \text{ psi}$$

$$S_T = 1.475 \times Q_A \text{ psi}$$

$$\psi_c = \frac{77.3 \times L \times Q_A}{(D_o^4 - D_i^4) \times E_s}$$

$$\psi_c = 0.00362 Q_A \text{ min. arc.}$$

$$\psi_c = 0.01144 \psi_s \text{ min. arc.}$$

Run No. 1

Run No. 2

Run No. 3

$$F_N = 81.75 \text{ lb. } F_N = 116.3 \text{ lb. } F_N = 167 \text{ lb.}$$

$$S_N = 5360 \text{ psi } S_N = 7640 \text{ psi } S_N = 10940 \text{ psi}$$

$Q_A$	$S_T$	$\psi_c$	$\psi_o$	$\psi_o$
120	177	0.4345	0.619	0.447
240	354	0.8695	1.317	0.825
300	443	1.090	- - -	1.304
360	532	1.304	- - -	1.237
420	620	1.520	- - -	- - -
480	710	1.740	- - -	1.674
600	886	2.177	- - -	2.200
720	1065	2.608	- - -	2.650
840	1243	3.040	- - -	3.200
900	1330	3.260	- - -	- - -
960	1420	3.470	- - -	- - -
1020	1505	3.690	- - -	- - -
1080	1595	3.910	- - -	- - -
1140	1680	4.130	- - -	- - -
1200	1770	4.350	- - -	- - -
1320	1950	4.775	- - -	- - -

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SPECIMEN NO.4 (continued)

		<u>Run No.4</u>		<u>Run No.5</u>		<u>Run No.6</u>	
		$F_N = 200.3 \text{ lb.}$		$F_N = 200.3 \text{ lb.}$		$F_N = 251.2 \text{ lb.}$	
		$S_N = 13130 \text{ psi}$		$S_N = 13130 \text{ psi}$		$S_N = 16450 \text{ psi}$	
$Q_A$	$S_T$	$\psi_c$	$\psi_o$	$\psi_o$	$\psi_o$		
120	177	0.4345	0.526	0.367	0.378		
240	354	0.8695	0.814	0.780	0.860		
300	443	1.090	0.953	- - -	- - -		
360	532	1.304	- - -	1.204	1.225		
420	620	1.520	1.306	- - -	- - -		
480	710	1.740	- - -	1.660	1.706		
600	886	2.177	2.085	2.061	2.130		
720	1065	2.608	2.520	2.400	2.590		
840	1243	3.040	- - -	2.956	3.050		
900	1330	3.260	3.130	- - -	- - -		
960	1420	3.470	- - -	3.370	3.525		
1020	1505	3.690	3.670	- - -	- - -		
1080	1595	3.910	- - -	3.850	4.000		
1140	1680	4.130	4.260	- - -	- - -		
1200	1770	4.350	- - -	4.275	4.340		
1320	1950	4.775	- - -	- - -	4.765		

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SPECIMEN NO.5

Material: C-1018 Steel

Surface Finish:  
4/0 paper

$$D_o = 0.2365"$$

$$D_i = 0.191"$$

$$L = 1.0078"$$

$$D_o^2 - D_i^2 = 0.01945$$

$$D_o^4 - D_i^4 = 0.001798$$

$$A = 0.01526 \text{ in}^2$$

$$S_N = \frac{F_N}{0.01526} \text{ psi}$$

$$S_T = 1.475 \times Q_A \text{ psi}$$

$$\psi_c = 0.00362 Q_A$$

$$\psi_o = 0.01144 \psi_s$$

Run No.1

$$F_N = 116.3 \text{ lb.}$$

$$S_N = 7640 \text{ psi}$$

Run No.2

$$F_N = 167 \text{ lb.}$$

$$S_N = 10940 \text{ psi}$$

$Q_A$	$S_T$	$\psi_c$	$\psi_o$	$\psi_o$
120	177	0.4345	0.378	0.446
150	221	0.543	- - -	- - -
240	354	0.8695	0.836	0.940
300	443	1.090	- - -	- - -
360	532	1.304	1.237	1.443
450	664	1.627	- - -	- - -
480	710	1.740	1.750	1.912
600	886	2.177	2.154	2.300
720	1065	2.608	2.610	2.656
750	1105	2.714	- - -	- - -
840	1243	3.040	3.120	3.208
900	1330	3.260	- - -	- - -
960	1420	3.470	3.640	3.676
1050	1550	3.800	- - -	- - -
1080	1595	3.910	- - -	4.420
1200	1770	4.350	- - -	- - -
1320	1950	4.775	- - -	- - -
1350	1990	4.885	- - -	- - -





SPECIMEN NO. 5 (continued)

Run No. 3

Run No. 4

$F_N = 200.2 \text{ lb.}$        $F_N = 251.2 \text{ lb.}$

$S_N = 14350 \text{ psi}$        $S_N = 16450 \text{ psi}$

$Q_A$	$S_T$	$\psi_c$	$\psi_o$	$\psi_o$
120	177	0.4345	0.344	- - -
150	221	0.543	- - -	0.493
240	354	0.8695	0.847	- - -
300	443	1.090	- - -	1.040
360	532	1.304	1.340	- - -
450	664	1.627	- - -	1.615
480	710	1.740	1.730	- - -
600	886	2.177	2.185	2.185
720	1065	2.608	2.635	- - -
750	1105	2.714	- - -	2.760
840	1243	3.040	3.080	- - -
900	1330	3.260	- - -	3.332
960	1420	3.470	3.550	- - -
1050	1550	3.800	- - -	3.800
1080	1595	3.910	4.020	- - -
1200	1770	4.350	4.465	4.500
1320	1950	4.775	4.930	- - -
1350	1990	4.885	- - -	5.020

[illegible]



## SPECIMEN NO.5

Run No.5

$$F_N = 168.16 \text{ lb.}$$

$$F_N = 76.4 \text{ kg}$$

$$S_N = 11020 \text{ psi}$$

$$s_n = 775 \text{ kg/cm}^2$$

$Q_A$	$s_t$	$\psi_R$	$\theta_R$	$f$
240	24.9	- - -	- - -	0.0293
360	37.4	- - -	- - -	0.0440
480	49.9	- - -	- - -	0.0587
600	62.3	- - -	- - -	0.0734
720	74.9	- - -	- - -	0.0880
840	87.5	- - -	- - -	0.1026
960	99.9	0.069	$5.44 \times 10^{-6}$	0.1172
1080	112.0	0.069	5.44 "	0.1320
1200	124.3	0.114	8.98 "	0.1466
1320	137.0	0.151	11.90 "	0.1613
1440	149.4	0.218	17.16 "	0.1760
1560	161.6	0.264	20.80 "	0.1906
1680	174.3	0.447	35.25 "	0.2050
1800	186.6	0.734	57.80 "	0.2200

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## SPECIMEN NO.5 (continued)

Run No.6 $F_N = 117.41 \text{ lb.}$  $F_N = 53.3 \text{ kg}$  $S_N = 770 \text{ psi}$  $s_n = 542 \text{ kg/cm}^2$ Run No.7 $F_N = 64.78 \text{ lb.}$  $F_N = 29.4 \text{ kg}$  $S_N = 4250 \text{ psi}$  $s_n = 299 \text{ kg/cm}^2$ 

$Q_A$	$\psi_R$	$\theta_R$	$f$	$Q_A$	$\psi_R$	$\theta_R$	$f$
240	- - -	- - -	- - -	240	0.183	$14.42 \times 10^{-6}$	0.076
360	0.034	$2.68 \times 10^{-6}$	0.042	360	0.183	"	0.114
480	0.046	3.63 "	0.063	480	0.412	32.50 "	0.152
600	0.218	17.20 "	0.084	600	0.734	57.80 "	0.191
720	0.183	14.42 "	0.105	720	0.734	57.80 "	0.228
840	0.367	28.90 "	0.126	840	0.768	60.60 "	0.266
960	0.458	36.10 "	0.147	960	1.752	138.2 "	0.305
1080	0.780	61.50 "	0.168				
1200	1.075	84.70 "	0.189				
1320	1.396	109.80 "	0.210				
1440	1.775	139.80 "	0.231				
1560	- - -	- - -	0.252				





## SPECIMEN NO. 6

Material: A-4140 Steel

Control Specimen  
(without interface)

$$D_o = 0.2315"$$

$$D_1 = 0.191"$$

$$L = 0.9063"$$

$$D_o^2 - D_1^2 = 0.01711$$

$$D_o^4 - D_1^4 = 0.001542$$

$$A = \frac{\pi}{4} (D_o^2 - D_1^2) = 0.01342 \text{ in}^2$$

$$S_N = \frac{F_N}{A} = \frac{F_N}{0.01342} \text{ psi}$$

$$S_T = 1.121 \times 10^{-2} \frac{D_o}{D_o^4 - D_1^4} \times Q_A$$

$$S_T = 1.684 Q_A \text{ psi}$$

$$\psi_c = \frac{77.3 \times L \times Q_A}{(D_o^4 - D_1^4) \times E_s}$$

$$\psi_c = 0.00382 Q_A$$

$$E_s = 11.9 \times 10^6 \text{ psi}$$

$$\psi_o = 0.01144 \psi_s$$

Run No. 1

$$F_N = 251.2 \text{ lb.}$$

$$S_N = 18700 \text{ psi}$$

$Q_A$	$S_T$	$\psi_c$	$\psi_o$
120	202.3	0.458	0.493
240	405	0.916	0.952
360	606.5	1.374	1.410
480	810	1.830	1.845
600	1010	2.290	2.315
720	1213	2.746	2.808
840	1416	3.205	3.323
960	1620	3.660	3.736
1080	1820	4.125	4.160

Run No. 2

$$F_N = 200.2 \text{ lb.}$$

$$S_N = 14900 \text{ psi}$$

$Q_A$	$S_T$	$\psi_c$	$\psi_o$
150	252.6	0.573	0.596
300	506	1.145	1.065
450	759	1.720	1.592
600	1010	2.290	2.200
750	1263	2.865	2.740
900	1516	3.440	3.320



# SPECIMEN NO. 7

Material: A-4140 Steel

Surface Finish  
As machined (lathe)

$$D_o = 0.2315''$$

$$D_i = 0.191''$$

$$L = 1.0078''$$

$$D_o^2 - D_i^2 = 0.01711$$

$$D_o^4 - D_i^4 = 0.001542$$

$$A = 0.01342 \text{ in}^2$$

$$S_N = \frac{F_N}{A} = \frac{F_N}{0.01342} \text{ psi}$$

$$S_T = 1.121 \times 10^{-2} \frac{D_o}{D_o^4 - D_i^4} \times Q_A$$

$$S_T = 1.684 \times Q_A \text{ psi}$$

$$\psi_c = \frac{77.3 \times L \times Q_A}{(D_o^4 - D_i^4) \times E_s}$$

$$\psi_c = 0.00425 Q_A$$

$$\psi_o = 0.01144 \psi_s$$

		<u>Run No. 1</u>		<u>Run No. 2</u>	
		$F_N = 116.3 \text{ lb.}$		$F_N = 167 \text{ lb.}$	
		$S_N = 8700 \text{ psi}$		$S_N = 12470 \text{ psi}$	
$Q_A$	$S_T$	$\psi_c$	$\psi_o$	$\psi_o$	
120	202	0.510	0.367	0.436	
240	404	1.020	0.849	0.895	
300	505	1.274	- - -	- - -	
360	606	1.530	1.410	1.490	
420	706	1.785	- - -	- - -	
480	808	2.040	1.937	2.140	
600	1010	2.546	2.510	2.720	
720	1212	3.057	- - -	3.370	
900	1515	3.820	- - -	- - -	
1020	1718	4.340	- - -	- - -	



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SPECIMEN NO. 7 (continued)

Run No. 3		Run No. 4	
$P_N = 200.2 \text{ lb.}$		$P_N = 251.2 \text{ lb.}$	
$S_N = 14950 \text{ psi}$		$S_N = 18740 \text{ psi}$	
$Q_A$	$S_T$	$\psi_e$	$\psi_o$
120	202	0.510	0.435
240	404	1.020	-
300	505	1.274	1.237
360	606	1.530	-
420	706	1.785	1.753
480	808	2.040	-
600	1010	2.546	2.450
720	1212	3.057	3.092
900	1515	3.820	4.075
1020	1718	4.340	-



SPECIMEN NO. 8

Material: A-4140 Steel

Surface Finish:  
No.1 emery paper

$$D_o = 0.2315"$$

$$D_i = 0.191"$$

$$L = 1.0078"$$

$$D_o^2 - D_i^2 = 0.0177$$

$$D_o^4 - D_i^4 = 0.001542$$

$$A = 0.01342 \text{ in}^2$$

$$S_N = \frac{F_N}{0.01342} \text{ psi}$$

$$S_T = 1.684 \times Q_A \text{ psi}$$

$$\psi_c = 0.00425 Q_A$$

$$\psi_o = 0.01144 \psi_s$$

		<u>Run No.1</u>		<u>Run No.2</u>	
		$F_N = 116.3 \text{ lb.}$		$F_N = 167 \text{ lb.}$	
		$S_N = 8700 \text{ psi}$		$S_N = 12470 \text{ psi}$	
$Q_A$	$S_T$	$\psi_c$	$\psi_o$	$\psi_o$	
150	252.5	0.637	0.618	0.676	
300	505	1.274	1.270	1.330	
450	758	1.910	1.890	1.923	
600	1010	2.546	2.576	2.550	
750	1262	3.185	3.260	3.170	
900	1515	3.820	- - -	- - -	
1050	1770	4.460	- - -	- - -	





SPECIMEN NO. 8 (continued)

<u>Run No. 3</u>				<u>Run No. 4</u>			
$F_N = 200.2 \text{ lb.}$				$F_N = 251.2 \text{ lb.}$			
$S_N = 14950 \text{ psi}$				$S_N = 18740 \text{ psi}$			
$Q_A$	$S_T$	$\psi_c$	$\psi_o$				
150	252.5	0.637	0.551		0.585		
300	505	1.274	1.250		1.144		
450	758	1.910	2.042		1.846		
600	1010	2.546	2.520		2.510		
750	1262	3.185	3.164		3.290		
900	1515	3.820	3.890		3.900		
1050	1770	4.460	- - -		4.510		



## SPECIMAN NO.8

Run No.7

$$F_N = 201.29 \text{ lb.}$$

$$F_N = 91.3 \text{ kg}$$

$$S_N = 15000 \text{ psi}$$

$$s_n = 1053 \text{ kg/cm}^2$$

$Q_A$	$s_t$	$\psi_R$	$\theta_R$	$f$
120	14.2	- - -	- - -	0.0124
240	28.4	- - -	- - -	0.0299
360	42.6	- - -	- - -	0.0373
480	56.8	- - -	- - -	0.0597
600	71.0	- - -	- - -	0.0621
720	85.3	- - -	- - -	0.0746
840	99.5	- - -	- - -	0.0870
960	113.5	0.011	$0.86 \times 10^{-6}$	0.0995
1080	127.7	0.046	3.59 "	0.1119
1200	142.0	0.057	4.45 "	0.1242
1320	156.2	0.092	7.18 "	0.1367
1440	170.4	0.092	7.18 "	0.1490
1560	184.5	0.138	10.75 "	0.1615
1680	198.7	0.252	19.65 "	0.1740
1800	213.0	0.412	32.15 "	0.1864
1920	227.0	0.803	62.60 "	0.1990
2040	241.0	0.859	67.00 "	0.2113
2160	256.0	1.512	118.0 "	0.2240
2280	270.0	2.660	207.4 "	0.2360
2400	284.0	- - -	- - -	0.2485



Table 1

Table 1

$\mu = 0.01$

$\sigma = 0.01$

$\mu = 0.01$

$\sigma = 0.01$

0.0000	- - -	- - -	0.0000	0.0000
0.0001	- - -	- - -	0.0001	0.0001
0.0002	- - -	- - -	0.0002	0.0002
0.0003	- - -	- - -	0.0003	0.0003
0.0004	- - -	- - -	0.0004	0.0004
0.0005	- - -	- - -	0.0005	0.0005
0.0006	- - -	- - -	0.0006	0.0006
0.0007	- - -	- - -	0.0007	0.0007
0.0008	- - -	- - -	0.0008	0.0008
0.0009	- - -	- - -	0.0009	0.0009
0.0010	- - -	- - -	0.0010	0.0010
0.0011	- - -	- - -	0.0011	0.0011
0.0012	- - -	- - -	0.0012	0.0012
0.0013	- - -	- - -	0.0013	0.0013
0.0014	- - -	- - -	0.0014	0.0014
0.0015	- - -	- - -	0.0015	0.0015
0.0016	- - -	- - -	0.0016	0.0016
0.0017	- - -	- - -	0.0017	0.0017
0.0018	- - -	- - -	0.0018	0.0018
0.0019	- - -	- - -	0.0019	0.0019
0.0020	- - -	- - -	0.0020	0.0020
0.0021	- - -	- - -	0.0021	0.0021
0.0022	- - -	- - -	0.0022	0.0022
0.0023	- - -	- - -	0.0023	0.0023
0.0024	- - -	- - -	0.0024	0.0024
0.0025	- - -	- - -	0.0025	0.0025
0.0026	- - -	- - -	0.0026	0.0026
0.0027	- - -	- - -	0.0027	0.0027
0.0028	- - -	- - -	0.0028	0.0028
0.0029	- - -	- - -	0.0029	0.0029
0.0030	- - -	- - -	0.0030	0.0030
0.0031	- - -	- - -	0.0031	0.0031
0.0032	- - -	- - -	0.0032	0.0032
0.0033	- - -	- - -	0.0033	0.0033
0.0034	- - -	- - -	0.0034	0.0034
0.0035	- - -	- - -	0.0035	0.0035
0.0036	- - -	- - -	0.0036	0.0036
0.0037	- - -	- - -	0.0037	0.0037
0.0038	- - -	- - -	0.0038	0.0038
0.0039	- - -	- - -	0.0039	0.0039
0.0040	- - -	- - -	0.0040	0.0040
0.0041	- - -	- - -	0.0041	0.0041
0.0042	- - -	- - -	0.0042	0.0042
0.0043	- - -	- - -	0.0043	0.0043
0.0044	- - -	- - -	0.0044	0.0044
0.0045	- - -	- - -	0.0045	0.0045
0.0046	- - -	- - -	0.0046	0.0046
0.0047	- - -	- - -	0.0047	0.0047
0.0048	- - -	- - -	0.0048	0.0048
0.0049	- - -	- - -	0.0049	0.0049
0.0050	- - -	- - -	0.0050	0.0050
0.0051	- - -	- - -	0.0051	0.0051
0.0052	- - -	- - -	0.0052	0.0052
0.0053	- - -	- - -	0.0053	0.0053
0.0054	- - -	- - -	0.0054	0.0054
0.0055	- - -	- - -	0.0055	0.0055
0.0056	- - -	- - -	0.0056	0.0056
0.0057	- - -	- - -	0.0057	0.0057
0.0058	- - -	- - -	0.0058	0.0058
0.0059	- - -	- - -	0.0059	0.0059
0.0060	- - -	- - -	0.0060	0.0060
0.0061	- - -	- - -	0.0061	0.0061
0.0062	- - -	- - -	0.0062	0.0062
0.0063	- - -	- - -	0.0063	0.0063
0.0064	- - -	- - -	0.0064	0.0064
0.0065	- - -	- - -	0.0065	0.0065
0.0066	- - -	- - -	0.0066	0.0066
0.0067	- - -	- - -	0.0067	0.0067
0.0068	- - -	- - -	0.0068	0.0068
0.0069	- - -	- - -	0.0069	0.0069
0.0070	- - -	- - -	0.0070	0.0070
0.0071	- - -	- - -	0.0071	0.0071
0.0072	- - -	- - -	0.0072	0.0072
0.0073	- - -	- - -	0.0073	0.0073
0.0074	- - -	- - -	0.0074	0.0074
0.0075	- - -	- - -	0.0075	0.0075
0.0076	- - -	- - -	0.0076	0.0076
0.0077	- - -	- - -	0.0077	0.0077
0.0078	- - -	- - -	0.0078	0.0078
0.0079	- - -	- - -	0.0079	0.0079
0.0080	- - -	- - -	0.0080	0.0080
0.0081	- - -	- - -	0.0081	0.0081
0.0082	- - -	- - -	0.0082	0.0082
0.0083	- - -	- - -	0.0083	0.0083
0.0084	- - -	- - -	0.0084	0.0084
0.0085	- - -	- - -	0.0085	0.0085
0.0086	- - -	- - -	0.0086	0.0086
0.0087	- - -	- - -	0.0087	0.0087
0.0088	- - -	- - -	0.0088	0.0088
0.0089	- - -	- - -	0.0089	0.0089
0.0090	- - -	- - -	0.0090	0.0090
0.0091	- - -	- - -	0.0091	0.0091
0.0092	- - -	- - -	0.0092	0.0092
0.0093	- - -	- - -	0.0093	0.0093
0.0094	- - -	- - -	0.0094	0.0094
0.0095	- - -	- - -	0.0095	0.0095
0.0096	- - -	- - -	0.0096	0.0096
0.0097	- - -	- - -	0.0097	0.0097
0.0098	- - -	- - -	0.0098	0.0098
0.0099	- - -	- - -	0.0099	0.0099
0.0100	- - -	- - -	0.0100	0.0100

Run No.8 $F_N = 168.16 \text{ lb.}$  $F_N = 76.4 \text{ kg}$  $S_N = 12540 \text{ psi}$  $s_n = 883 \text{ kg/cm}^2$ 

$\zeta_A$	$\phi_R$	$\theta_R$	$r$	$Q_A$	$\phi_R$	$\theta_R$	$r$
120	- - -	- - -	0.0149	120	- - -	- - -	0.0213
240	- - -	- - -	0.0298	240	- - -	- - -	0.0426
360	- - -	- - -	0.0446	360	0.138	$10.75 \times 10^{-6}$	0.0640
480	- - -	- - -	0.0595	480	0.252	"	0.0852
600	0.114	$8.89 \times 10^{-6}$	0.0745	600	0.653	"	0.1066
720	0.401	31.25	0.0894	720	1.042	81.30	0.1280
840	0.481	37.50	0.1042	840	1.820	141.8	0.1492
960	0.805	70.60	0.1190	960	3.240	252.5	0.1705
1080	0.974	76.00	0.1340	1080	- - -	- - -	0.1916
1200	0.940	73.35	0.1487				
1320	1.132	88.30	0.1636				
1440	1.317	102.6	0.1786				
1560	1.545	120.5	0.1935				
1680	2.395	186.6	0.2085				
1800	2.575	200.8	0.2232				
1920	2.740	214.0	0.2380				
2040	3.045	237.5	0.2530				
2160	5.440	424.0	0.2680				
2280	- - -	- - -	0.2830				

Run No.9 $F_N = 117.41 \text{ lb.}$  $F_N = 53.3 \text{ kg}$  $S_N = 8760 \text{ psi}$  $s_n = 616 \text{ kg/cm}^2$ 

$\zeta_A$	$\phi_R$	$\theta_R$	$r$
120	- - -	- - -	0.0213
240	- - -	- - -	0.0426
360	0.138	$10.75 \times 10^{-6}$	0.0640
480	0.252	"	0.0852
600	0.653	"	0.1066
720	1.042	81.30	0.1280
840	1.820	141.8	0.1492
960	3.240	252.5	0.1705
1080	- - -	- - -	0.1916

(continued) Code numbers

Code

001 53.05.1.1 100

002 53.05.1.2 100

003 53.05.1.3 100

004 53.05.1.4 100

Code	Code	Code	Code
005	53.05.1.5	100	006
007	53.05.1.6	100	008
009	53.05.1.7	100	010
011	53.05.1.8	100	012
013	53.05.1.9	100	014
015	53.05.1.10	100	016
017	53.05.1.11	100	018
019	53.05.1.12	100	020
021	53.05.1.13	100	022
023	53.05.1.14	100	024
025	53.05.1.15	100	026
027	53.05.1.16	100	028
029	53.05.1.17	100	030
031	53.05.1.18	100	032
033	53.05.1.19	100	034
035	53.05.1.20	100	036
037	53.05.1.21	100	038
039	53.05.1.22	100	040
041	53.05.1.23	100	042
043	53.05.1.24	100	044
045	53.05.1.25	100	046
047	53.05.1.26	100	048
049	53.05.1.27	100	050
051	53.05.1.28	100	052
053	53.05.1.29	100	054
055	53.05.1.30	100	056
057	53.05.1.31	100	058
059	53.05.1.32	100	060
061	53.05.1.33	100	062
063	53.05.1.34	100	064
065	53.05.1.35	100	066
067	53.05.1.36	100	068
069	53.05.1.37	100	070
071	53.05.1.38	100	072
073	53.05.1.39	100	074
075	53.05.1.40	100	076
077	53.05.1.41	100	078
079	53.05.1.42	100	080
081	53.05.1.43	100	082
083	53.05.1.44	100	084
085	53.05.1.45	100	086
087	53.05.1.46	100	088
089	53.05.1.47	100	090
091	53.05.1.48	100	092
093	53.05.1.49	100	094
095	53.05.1.50	100	096
097	53.05.1.51	100	098
099	53.05.1.52	100	100

Code

001 53.05.1.1 100

002 53.05.1.2 100

003 53.05.1.3 100

004 53.05.1.4 100

Code	Code	Code	Code
005	53.05.1.5	100	006
007	53.05.1.6	100	008
009	53.05.1.7	100	010
011	53.05.1.8	100	012
013	53.05.1.9	100	014
015	53.05.1.10	100	016
017	53.05.1.11	100	018
019	53.05.1.12	100	020
021	53.05.1.13	100	022
023	53.05.1.14	100	024
025	53.05.1.15	100	026
027	53.05.1.16	100	028
029	53.05.1.17	100	030
031	53.05.1.18	100	032
033	53.05.1.19	100	034
035	53.05.1.20	100	036
037	53.05.1.21	100	038
039	53.05.1.22	100	040
041	53.05.1.23	100	042
043	53.05.1.24	100	044
045	53.05.1.25	100	046
047	53.05.1.26	100	048
049	53.05.1.27	100	050
051	53.05.1.28	100	052
053	53.05.1.29	100	054
055	53.05.1.30	100	056
057	53.05.1.31	100	058
059	53.05.1.32	100	060
061	53.05.1.33	100	062
063	53.05.1.34	100	064
065	53.05.1.35	100	066
067	53.05.1.36	100	068
069	53.05.1.37	100	070
071	53.05.1.38	100	072
073	53.05.1.39	100	074
075	53.05.1.40	100	076
077	53.05.1.41	100	078
079	53.05.1.42	100	080
081	53.05.1.43	100	082
083	53.05.1.44	100	084
085	53.05.1.45	100	086
087	53.05.1.46	100	088
089	53.05.1.47	100	090
091	53.05.1.48	100	092
093	53.05.1.49	100	094
095	53.05.1.50	100	096
097	53.05.1.51	100	098
099	53.05.1.52	100	100

## SPECIMEN NO.8 (continued)

Run No.10

$$F_N = 64.78 \text{ lb.}$$

$$F_N = 29.4 \text{ kg}$$

$$S_N = 4835 \text{ psi}$$

$$s_n = 340 \text{ kg/cm}^2$$

$Q_A$	$\psi_R$	$\theta_R$	$f$
120	- - -	- - -	0.0386
240	0.172	$13.40 \times 10^{-6}$	0.0773
360	0.836	65.20 "	0.1160
480	8.850	690.0 "	0.1545
600	- - -	- - -	0.1930



# TABLE 1. Summary of results.

## Summary of results

$$100 \times \frac{1}{n} \sum_{i=1}^n \frac{1}{x_i} = 100 \times \frac{1}{n} \sum_{i=1}^n \frac{1}{x_i}$$

$$100 \times \frac{1}{n} \sum_{i=1}^n \frac{1}{x_i} = 100 \times \frac{1}{n} \sum_{i=1}^n \frac{1}{x_i}$$

$$100 \times \frac{1}{n} \sum_{i=1}^n \frac{1}{x_i} = 100 \times \frac{1}{n} \sum_{i=1}^n \frac{1}{x_i}$$

$$100 \times \frac{1}{n} \sum_{i=1}^n \frac{1}{x_i} = 100 \times \frac{1}{n} \sum_{i=1}^n \frac{1}{x_i}$$

$\frac{1}{n} \sum_{i=1}^n \frac{1}{x_i}$	$\frac{1}{n} \sum_{i=1}^n \frac{1}{x_i}$	$\frac{1}{n} \sum_{i=1}^n \frac{1}{x_i}$	$\frac{1}{n} \sum_{i=1}^n \frac{1}{x_i}$
0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000

SPECIMEN NO.9

Material: A-4140 Steel

Surface Finish:  
2/0 paper

$$D_o = 0.2315"$$

$$D_i = 0.191"$$

$$L = 1.0078"$$

$$D_o^2 - D_i^2 = 0.01711$$

$$D_o^4 - D_i^4 = 0.001542$$

$$A = 0.01342 \text{ in}^2$$

$$S_N = \frac{F_N}{0.01342}$$

$$S_T = 1.684 \times Q_A \text{ psi}$$

$$\psi_G = 0.00425 Q_A$$

$$\psi_O = 0.01144 \psi_S$$

Run No.1

$$F_N = 116.3 \text{ lb.}$$

$$S_N = 8700 \text{ psi}$$

Run No.2

$$F_N = 167 \text{ lb.}$$

$$S_N = 12470 \text{ psi}$$

$Q_A$	$S_T$	$\psi_C$	$\psi_O$	$\psi_O$
150	252.5	0.637	0.607	0.425
300	505	1.274	1.306	1.240
450	758	1.910	2.027	1.800
600	1010	2.546	2.635	2.363
750	1262	3.185	- - -	2.910
900	1515	3.820	- - -	3.650
1050	1770	4.460	- - -	4.410

PROBLEM SET 1

Exercises 1.1-1.10

1.1. Let  $f: \mathbb{R} \rightarrow \mathbb{R}$  be a function. Show that  $f$  is continuous at  $a \in \mathbb{R}$  if and only if  $f$  is continuous at  $a$  in the  $\epsilon$ - $\delta$  sense.

1.2. Let  $f: \mathbb{R} \rightarrow \mathbb{R}$  be a function. Show that  $f$  is continuous at  $a \in \mathbb{R}$  if and only if  $f$  is continuous at  $a$  in the  $\epsilon$ - $\delta$  sense.

1.3. Let  $f: \mathbb{R} \rightarrow \mathbb{R}$  be a function. Show that  $f$  is continuous at  $a \in \mathbb{R}$  if and only if  $f$  is continuous at  $a$  in the  $\epsilon$ - $\delta$  sense.

1.4. Let  $f: \mathbb{R} \rightarrow \mathbb{R}$  be a function. Show that  $f$  is continuous at  $a \in \mathbb{R}$  if and only if  $f$  is continuous at  $a$  in the  $\epsilon$ - $\delta$  sense.

1.5. Let  $f: \mathbb{R} \rightarrow \mathbb{R}$  be a function. Show that  $f$  is continuous at  $a \in \mathbb{R}$  if and only if  $f$  is continuous at  $a$  in the  $\epsilon$ - $\delta$  sense.

1.6. Let  $f: \mathbb{R} \rightarrow \mathbb{R}$  be a function. Show that  $f$  is continuous at  $a \in \mathbb{R}$  if and only if  $f$  is continuous at  $a$  in the  $\epsilon$ - $\delta$  sense.

1.7. Let  $f: \mathbb{R} \rightarrow \mathbb{R}$  be a function. Show that  $f$  is continuous at  $a \in \mathbb{R}$  if and only if  $f$  is continuous at  $a$  in the  $\epsilon$ - $\delta$  sense.

1.8. Let  $f: \mathbb{R} \rightarrow \mathbb{R}$  be a function. Show that  $f$  is continuous at  $a \in \mathbb{R}$  if and only if  $f$  is continuous at  $a$  in the  $\epsilon$ - $\delta$  sense.

1.9. Let  $f: \mathbb{R} \rightarrow \mathbb{R}$  be a function. Show that  $f$  is continuous at  $a \in \mathbb{R}$  if and only if  $f$  is continuous at  $a$  in the  $\epsilon$ - $\delta$  sense.

1.10. Let  $f: \mathbb{R} \rightarrow \mathbb{R}$  be a function. Show that  $f$  is continuous at  $a \in \mathbb{R}$  if and only if  $f$  is continuous at  $a$  in the  $\epsilon$ - $\delta$  sense.

1.11. Let  $f: \mathbb{R} \rightarrow \mathbb{R}$  be a function. Show that  $f$  is continuous at  $a \in \mathbb{R}$  if and only if  $f$  is continuous at  $a$  in the  $\epsilon$ - $\delta$  sense.

1.12. Let  $f: \mathbb{R} \rightarrow \mathbb{R}$  be a function. Show that  $f$  is continuous at  $a \in \mathbb{R}$  if and only if  $f$  is continuous at  $a$  in the  $\epsilon$ - $\delta$  sense.

SPECIMEN NO. 9 (continued)

		<u>Run No. 3</u>		<u>Run No. 4</u>	
		$F_N = 200.2 \text{ lb.}$		$F_N = 251.2 \text{ lb.}$	
		$S_N = 14950 \text{ psi}$		$S_N = 18740 \text{ psi}$	
$Q_A$	$S_T$	$\psi_c$	$\psi_o$	$\psi_o$	
150	252.5	0.637	0.551	0.768	
300	505	1.274	1.390	1.240	
450	758	1.910	1.893	2.009	
600	1010	2.546	2.480	2.560	
750	1262	3.185	3.020	3.155	
900	1515	3.820	3.760	- - -	
1050	1770	4.460	- - -	- - -	





SPECIMEN NO. 10.

Material: 2S Aluminum

Control Specimen:  
(without interface)

$$D_o = 0.2365"$$

$$D_1 = 0.191"$$

$$L = 0.9844"$$

$$D_o^2 - D_1^2 = 0.01945$$

$$D_o^4 - D_1^4 = 0.001798$$

$$A = \frac{\pi}{4} (D_o^2 - D_1^2) = 0.01526$$

$$S_H = \frac{F_H}{A} = \frac{F_H}{0.01526} \text{ psi}$$

$$S_T = 1.121 \times 10^{-2} \frac{D_o^4 - D_1^4}{D_o^4 - D_1^4} \times C_A$$

$$S_T = 1.475 \times C_A \text{ psi}$$

$$\psi_c = \frac{77.3 \times L \times C_A}{(D_o^4 - D_1^4) \times E_S}$$

$$L_S = 3.7 \times 10^6 \text{ psi}$$

$$\psi_c = 0.01145 \times C_A$$

$$\psi_o = 0.01144 \psi_s$$

Run No. 1

$$F_H = 116.3 \text{ lb.}$$

$$S_H = 7640 \text{ psi}$$

$$\psi_o$$

$$S_T$$

$$C_A$$

$$\psi_c$$

$$\psi_R$$

$$\psi_o$$

$$\psi_R$$

Run No. 2

$$F_H = 167 \text{ lb.}$$

$$S_H = 10940 \text{ psi}$$

$$\psi_o$$

$$\psi_R$$

$\psi_R$  = Residual Twist.

Sight edges on indicator arms failed to return to zero index on removal of torque.  $\psi_R$  is residual twist remaining in specimen after removal of torque.

STANDARD MEASUREMENTS

MEASUREMENTS OF DISTANCE

MEASUREMENTS OF DISTANCE  
(continued from previous page)

$$20000.0 = 0$$

$$1000.0 = 10$$

$$11000.0 = 1$$

$$20000.0 = 20 - 20$$

$$20000.0 = 10 - 10$$

$$20000.0 = (20 - 20) \frac{1}{1} = 1$$

$$20000.0 = \frac{1}{1} = 1$$

$$20000.0 = \frac{1}{1} = 1$$

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STANDARD MEASUREMENTS

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SPECIMEN NO.11

Material: Copper

Control Specimen:  
(without interface)

$$D_o = 0.2368''$$

$$D_i = 0.191''$$

$$L = 1.01563''$$

$$D_o^2 - D_i^2 = 0.01959$$

$$D_o^4 - D_i^4 = 0.001814$$

$$A = \frac{\pi}{4} (D_o^2 - D_i^2) = 0.01537$$

$$S_N = \frac{F_N}{A} \text{ psi}$$

$$S_T = 1.121 \times 10^{-2} \frac{D_o}{D_o^4 - D_i^4} Q_A$$

$$S_T = 1.464 \times Q_A \text{ psi}$$

$$\psi_c = \frac{77.3 \times L \times Q_A}{(D_o^4 - D_i^4) \times E_s}$$

$$E_s = 6.0 \times 10^6 \text{ psi}$$

$$\psi_c = 0.00722 Q_A$$

$$\psi_o = 0.01144 \psi_s$$

Run No.1

$$F_N = 200 \text{ lb.}$$

$$S_N = 13020 \text{ psi}$$

Run No.2

$$F_N = 250 \text{ lb.}$$

$$S_N = 16270 \text{ psi}$$

Run No.3

$$F_N = 200 \text{ lb.}$$

$$S_N = 13020 \text{ psi}$$

$Q_A$	$S_T$	$\psi_o$	$\psi_c$	$\psi_o$	$\psi_R$	$Q_A$	$\psi_R$	$Q_A$	$\psi_R$
30	44	0.332	0.216	0.332	- - -	30	- - -	120	0.050
60	88	0.550	0.434	0.550	0.040	60	0.046	240	0.050
90	132	0.780	0.650	0.780	0.160	90	- - -	360	0.092
120	176	0.974	0.866	0.974	0.040	120	0.080	480	0.090
150	220	1.052	1.082	1.052	0.060	150	- - -	600	0.103
180	264	1.340	1.300	1.340	0.161	180	0.050	720	0.217
210	308	1.580	1.515	1.580	0.320	210	- - -	840	0.320
240	352	1.763	1.730	1.763	0.252	240	0.069	960	0.310
270	396	1.980	1.950	1.980	0.321	270	- - -	1080	0.286
300	440	2.185	2.165	2.185	0.424	300	0.172	1200	0.458
330	484	2.415	2.380	2.415	0.401	330	- - -	1320	0.573
360	527	2.610	2.596	2.610	0.424	360	0.092	1440	0.652
390	572	2.840	2.813	2.840	0.504	390	- - -	1560	0.812
420	615	2.986	3.030	2.986	0.550	420	0.252	1680	0.995
450	660	3.220	3.245	3.220	0.642	450	- - -	1800	0.965



$\mathbb{E}^H = 500 \text{ TP.}$        $\mathbb{E}^H = 520 \text{ TP.}$        $\mathbb{E}^H = 500 \text{ TP.}$

Year	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
1900	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	

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## SPECIMEN NO.12

Run No.1

$$F_N = 31.86 \text{ lb.}$$

$$F_N = 14.4 \text{ kg}$$

$$S_E = 2375 \text{ psi}$$

$$s_n = 167 \text{ kg/cm}^2$$

$Q_A$	$s_t$	$\psi_R$	$\theta_R$	$f$
120	14.2	- - -	- - -	0.0785
240	28.4	0.046	$3.59 \times 10^{-6}$	0.1570
360	42.6	0.149	11.60 "	0.2358
480	56.8	0.825	64.40 "	0.3140
600	71.0	- - -	- - -	0.3930
720	85.3			
840	99.5			
960	113.5			
1080	127.7			
1200	142.0			
1320	156.2			
1440	170.4			
1560	184.5			
1680	198.7			
1800	213.0			

Material: A-4140 Steel

Surface Finish: 4/0 paper

Material: 1000 lbs.  
Sutace Fiber 1000 lbs.

## SPECIMEN NO.12 (continued)

Run No.2 $F_N = 53.8 \text{ lb.}$  $F_N = 24.2 \text{ kg}$  $S_N = 3980 \text{ psi}$  $s_n = 280 \text{ kg/cm}^2$ 

$Q_A$	$\psi_R$	$\theta_R$	$f$
120	0.114	$8.89 \times 10^{-6}$	0.0469
240	0.184	14.34	"
360	0.321	25.05	"
480	0.860	67.15	"
600	2.580	201.3	"
720	3.085	240.6	"
840	- - -	- - -	0.3280

Run No.3 $F_N = 117.41 \text{ lb.}$  $F_N = 53.3 \text{ kg}$  $S_N = 8760 \text{ psi}$  $s_n = 616 \text{ kg/cm}^2$ 

$Q_A$	$\psi_R$	$\theta_R$	$f$
120	- - -	- - -	0.0213
240	- - -	- - -	0.0426
360	0.011	$0.86 \times 10^{-6}$	0.0640
480	0.046	3.59	0.0862
600	0.184	14.34	0.1066
720	0.665	51.90	0.1280
840	0.688	53.65	0.1492
960	0.872	68.00	0.1705
1080	1.053	82.20	0.1916
1200	1.144	89.30	0.2130
1320	1.707	133.0	0.2340
1440	2.096	163.3	0.2555
1560	3.060	238.6	0.2768
1680	7.550	589.0	0.2980
1800	- - -	- - -	0.3190



add 1A.V11 = R<sup>1</sup>

24 6.00 = R<sup>1</sup>

25 00F8 = R<sup>2</sup>

26 00F8 = R<sup>2</sup>

27 00F8 = R<sup>2</sup>

28 00F8 = R<sup>2</sup>

29 00F8 = R<sup>2</sup>

30 00F8 = R<sup>2</sup>

31 00F8 = R<sup>2</sup>

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# SPECIMEN NO.13

Material: Copper

Surface Finish: No.1 Paper

$$D_o = 0.2359"$$

$$D_i = 0.191"$$

$$L = 1.000"$$

$$S_N = \frac{F_N}{0.01505} \text{ psi}$$

$$S_T = 1.495 \times Q_A \text{ psi}$$

$$\psi_c = 0.00708 \times Q_A$$

$$I_s = 6.0 \times 10^6 \text{ psi}$$

$$\psi_o = 0.01144 \psi_s$$

## Run No.2

$$F_N = 201.9 \text{ lb.}$$

$$S_N = 13360 \text{ psi}$$

$$S_T$$

$$\psi_o$$

$$\psi_c$$

$$Q_A$$

$$\psi_o$$

$$Q_A$$

$$\psi_o$$

## Run No.1

$$F_N = 251 \text{ lb.}$$

$$S_N = 16700 \text{ psi}$$

$$Q_A$$

$$\psi_o$$

$$Q_A$$

$$\psi_o$$

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$\phi = 0.0109 \times C$

$\alpha = 0.9$

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## SPECIMEN NO.13

Run No.1

$$F_N = 168.16 \text{ lb.}$$

$$F_N = 76.4 \text{ kg}$$

$$S_N = 11170 \text{ psi}$$

$$s_n = 785 \text{ kg/cm}^2$$

$Q_A$	$s_t$	$\psi_R$	$\theta_R$	$f$
60	6.3	- - -	- - -	0.0074
120	12.6	0.080	$6.34 \times 10^{-6}$	0.0147
180	18.9	0.103	8.15 "	0.0220
240	25.2	0.114	9.04 "	0.0294
300	31.5	- - -	- - -	0.0367

Run No.5

$$F_N = 117.41 \text{ lb.}$$

$$F_N = 53.3 \text{ kg}$$

$$S_N = 7800 \text{ psi}$$

$$s_n = 548 \text{ kg/cm}^2$$

$Q_A$	$\psi_R$	$\theta_R$	$f$
120	- - -	- - -	0.0211
240	0.023	$1.81 \times 10^{-6}$	0.0421
360	0.126	9.95 "	0.0632
480	0.149	11.76 "	0.0842
600	0.183	14.45 "	0.1052
720	0.298	23.50 "	0.1264
840	- - -	- - -	0.1475



Table 1

Table 2

Table 3

Table 4

Table 5

Table 6

1700.0	...	...	...	...
1800.0	...	...	...	...
1900.0	...	...	...	...
2000.0	...	...	...	...
2100.0	...	...	...	...
2200.0	...	...	...	...

Table 7

Table 8

Table 9

Table 10

Table 11

1100.0	...	...	...
1200.0	...	...	...
1300.0	...	...	...
1400.0	...	...	...
1500.0	...	...	...
1600.0	...	...	...
1700.0	...	...	...
1800.0	...	...	...

## SPECIMEN NO.13 (continued)

Run No.2 $F_N = 201.29 \text{ lb.}$  $F_N = 91.3 \text{ kg}$  $S_N = 13360 \text{ psi}$  $s_n = 939 \text{ kg/cm}^2$ 

$Q_A$	$\psi_R$	$\theta_R$	$f$	$Q_A$	$\psi_R$	$\theta_R$	$f$
60	- - -	- - -	0.00615	120	- - -	- - -	0.0098
120	- - -	- - -	0.0123	240	- - -	- - -	0.0197
180	0.149	$11.76 \times 10^{-6}$	0.0184	360	0.114	$9.00 \times 10^{-6}$	0.0295
240	0.069	"	0.0246	480	0.046	"	0.0394
300	0.149	"	0.0308	600	0.183	"	0.0493
360	0.137	"	0.0369	720	0.435	"	0.0640
420	0.309	"	0.0430	840	0.618	"	0.0690
480	0.275	"	0.0491	960	- - -	- - -	- - -
540	0.286	"	0.0553				
600	0.367	"	0.0615				
660	0.458	"	0.0676				
720	0.435	"	0.0737				
780	0.435	"	0.0800				
840	0.446	"	0.0860				
960	- - -	- - -	- - -				

Run No.3 $F_N = 251 \text{ lb.}$  $F_N = 114.0 \text{ kg}$  $S_N = 16700 \text{ psi}$  $s_n = 1172 \text{ kg/cm}^2$ 

$Q_A$	$\psi_R$	$\theta_R$	$f$
120	- - -	- - -	0.0098
240	- - -	- - -	0.0197
360	0.114	$9.00 \times 10^{-6}$	0.0295
480	0.046	"	0.0394
600	0.183	"	0.0493
720	0.435	"	0.0640
840	0.618	"	0.0690
960	- - -	- - -	- - -



## SPECIMEN NO.13 (continued)

Run No.6 $F_N = 168.16 \text{ lb.}$  $F_N = 76.4 \text{ kg}$  $S_N = 11170 \text{ psi}$  $s_n = 785 \text{ kg/cm}^2$ 

$Q_A$	$\phi_R$	$\theta_R$	$f$
120	- - -	- - -	0.0147
240	0.092	$7.24 \times 10^{-6}$	0.0294
360	0.080	6.33	0.0441
480	0.057	4.52	0.0588
600	0.092	7.24	0.0735
720	0.195	15.35	0.0882
840	0.481	38.00	0.1028
960	0.722	57.00	0.1175
1080	0.929	73.30	0.1320
1200	- - -	- - -	0.1470

Run No.7 $F_N = 201.29 \text{ lb.}$  $F_N = 91.3 \text{ kg}$  $S_N = 13360 \text{ psi}$  $s_n = 939 \text{ kg/cm}^2$ 

$Q_A$	$\phi_R$	$\theta_R$	$f$
120	- - -	- - -	0.0123
240	0.011	$0.90 \times 10^{-6}$	0.0246
360	0.092	7.24	0.0369
480	0.172	13.56	0.0491
600	0.149	11.76	0.0615
720	0.218	17.15	0.0737
840	0.321	25.30	0.0860
960	0.458	36.10	0.0983
1080	0.493	38.90	0.1105
1200	0.550	43.30	0.1228
1320	0.825	65.10	0.1350
1440	2.120	167.0	0.1473
1560	2.820	222.4	0.1596
1680	- - -	- - -	0.1720





SPECIMEN NO.14

Material: Copper

Surface Finish: 2/o Paper

$$D_o = 0.2359"$$

$$D_i = 0.191"$$

$$L = 1.000"$$

$$S_N = \frac{F_N}{0.01505} \text{ psi}$$

$$S_T = 1.495 \times Q_A \text{ psi}$$

$$\psi_c = 0.00708 \times Q_A$$

$$E_s = 6.0 \times 10^6 \text{ psi}$$

$$\psi_o = 0.01144 \psi_s$$

Run No.1

$$F_N = 64.8 \text{ lb.}$$

$$S_N = 4300 \text{ psi}$$

Run No.2

$$F_N = 117.4 \text{ lb.}$$

$$S_N = 7800 \text{ psi}$$

$Q_A$	$S_T$	$\psi_c$	$\psi_o$	$Q_A$	$\psi_o$
120	180	0.850	0.837	120	0.756
240	359	1.700	1.740	240	1.560
360	539	2.550	2.715	360	2.510
480	719	3.400	3.910	480	3.480
600	900	4.250	5.320	600	4.500
720	1076	5.100		720	5.730
840	1257	5.950		840	5.970
960	1436	6.800			
1080	1614	7.650			

# ALPHA PARTICLES

range in air

range in air

ALPHA PARTICLES

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SPECIMEN NO. 14 (continued)

Run No. 3				Run No. 4				Run No. 5			
$F_N = 168.2 \text{ lb.}$				$F_N = 201.3 \text{ lb.}$				$F_N = 231.68 \text{ lb.}$			
$S_N = 11170 \text{ psi}$				$S_N = 13360 \text{ psi}$				$S_N = 15400 \text{ psi}$			
$Q_A$	$S_T$	$\psi_c$	$\psi_o$	$Q_A$	$\psi_o$	$Q_A$	$\psi_o$	$Q_A$	$\psi_o$	$Q_A$	$\psi_o$
120	180	0.850	0.733	120	0.780	120	0.882	120	0.882	120	0.882
240	359	1.700	1.525	240	1.696	240	1.294	240	1.294	240	1.294
360	539	2.550	2.350	360	2.570	360	2.610	360	2.610	360	2.610
480	719	3.400	3.080	480	3.475	480	3.540	480	3.540	480	3.540
600	900	4.250	4.040	600	4.290	600	4.380	600	4.380	600	4.380
720	1076	5.100	4.940	720	5.360	720	5.333	720	5.333	720	5.333
840	1257	5.950	5.740	840	6.310	840	6.230	840	6.230	840	6.230
960	1436	6.800	6.720	960	7.230	960	7.250	960	7.250	960	7.250
1080	1614	7.650	-	-	-	-	-	-	-	-	-

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## SPECIMEN NO.14

Run No.1

$$F_N = 64.78 \text{ lb.}$$

$$F_N = 29.4 \text{ kg}$$

$$S_N = 4300 \text{ psi}$$

$$s_n = 302 \text{ kg/cm}^2$$

$Q_A$	$s_t$	$\psi_R$	$\theta_R$	$f$
120	12.6	- - -	- - -	0.0382
240	25.2	0.183	$14.46 \times 10^{-6}$	0.0763
360	37.8	0.298	23.50 "	0.1144
480	50.5	0.505	39.88 "	0.1526
600	63.1	3.310	261.5 "	0.1910
720	75.6	- - -	- - -	0.2290
840	88.4			
960	101.0			
1080	113.6			
1200	126.1			
1320	138.9			
1440	151.2			
1560	164.0			
1680	176.6			
1800	189.0			
1920	201.5			
2040	214.2			
2160	226.8			
2280	239.5			
2400	252.0			
2520	264.0			



## SPECIMEN NO. 14 (continued)

Run No. 2 $P_N = 117.41 \text{ lb.}$  $P_N = 53.3 \text{ kg}$  $S_N = 7800 \text{ psi}$  $s_n = 548 \text{ kg/cm}^2$ 

$Q_A$	$\psi_R$	$\theta_R$	$f$
120	- - -	- - -	0.0211
240	0.057	$4.50 \times 10^{-6}$	0.0421
360	0.184	14.50	0.0632
480	0.378	29.80	0.0842
600	0.653	51.50	0.1052
720	1.032	81.50	0.1264
840	1.420	112.0	0.1475
960	3.370	294.3	0.1683
1080	10.000	790.0	0.1893
1200	- - -	- - -	0.2100

Run No. 3 $P_N = 168.16 \text{ lb.}$  $P_N = 764 \text{ kg}$  $S_N = 11170 \text{ psi}$  $s_n = 785 \text{ kg/cm}^2$ 

$Q_A$	$\psi_R$	$\theta_R$	$f$
120	- - -	- - -	0.0147
240	- - -	- - -	0.0294
360	- - -	- - -	0.0441
480	- - -	- - -	0.0588
600	0.057	$4.50 \times 10^{-6}$	0.0735
720	0.149	11.76	0.0882
840	0.172	13.56	0.1028
960	0.241	19.00	0.1175
1080	0.355	28.00	0.1320
1200	0.390	30.78	0.1470
1320	0.424	33.24	0.1616
1440	0.734	57.90	0.1764
1560	- - -	- - -	0.1910





Run No. 4 $P_H = 201.29 \text{ lb.}$  $F_H = 91.3 \text{ kg}$  $S_H = 13360 \text{ psi}$  $s_H = 939 \text{ kg/cm}^2$ 

$Q_A$	$\psi_R$	$\theta_R$	$f$	$Q_A$	$\psi_R$	$\theta_R$	$f$
120	--	--	0.0123	120	--	--	0.0107
240	0.184	$14.50 \times 10^{-6}$	0.0246	240	0.160	$12.52 \times 10^{-6}$	0.0214
360	0.264	"	0.0369	360	0.321	"	0.0320
480	0.435	"	0.0491	480	0.424	"	0.0427
600	0.550	"	0.0615	600	0.493	"	0.0535
720	0.723	"	0.0737	720	0.619	"	0.0640
840	0.769	"	0.0860	840	0.756	"	0.0748
960	0.906	"	0.0983	960	0.974	"	0.0855
1080	1.007	"	0.1105	1080	0.962	"	0.0962
1200	1.087	"	0.1228	1200	1.100	"	0.1069
1320	1.363	"	0.1350	1320	1.340	"	0.1175
1440	1.546	"	0.1473	1440	1.350	"	0.1280
1560	2.040	"	0.1596	1560	1.593	"	0.1390
1680	2.222	"	0.1720	1680	1.775	"	0.1495
1800	2.500	"	0.1845	1800	1.890	"	0.1600
1920	2.960	"	0.1966	1920	2.060	"	0.1708
2040	--	--	0.2090	2040	2.325	"	0.1815

Run No. 5 $P_H = 231.68 \text{ lb.}$  $F_H = 105.0 \text{ kg}$  $S_H = 15400 \text{ psi}$  $s_H = 1080 \text{ kg/cm}^2$ 

$Q_A$	$\psi_R$	$\theta_R$	$f$	$Q_A$	$\psi_R$	$\theta_R$	$f$
120	--	--	--	120	--	--	0.0107
240	0.160	$12.52 \times 10^{-6}$	0.0214	240	0.160	$12.52 \times 10^{-6}$	0.0214
360	0.321	"	0.0320	360	0.321	"	0.0320
480	0.424	"	0.0427	480	0.424	"	0.0427
600	0.493	"	0.0535	600	0.493	"	0.0535
720	0.619	"	0.0640	720	0.619	"	0.0640
840	0.756	"	0.0748	840	0.756	"	0.0748
960	0.974	"	0.0855	960	0.974	"	0.0855
1080	0.962	"	0.0962	1080	0.962	"	0.0962
1200	1.100	"	0.1069	1200	1.100	"	0.1069
1320	1.340	"	0.1175	1320	1.340	"	0.1175
1440	1.350	"	0.1280	1440	1.350	"	0.1280
1560	1.593	"	0.1390	1560	1.593	"	0.1390
1680	1.775	"	0.1495	1680	1.775	"	0.1495
1800	1.890	"	0.1600	1800	1.890	"	0.1600
1920	2.060	"	0.1708	1920	2.060	"	0.1708
2040	2.325	"	0.1815	2040	2.325	"	0.1815
	2.690	"	0.1920		2.690	"	0.1920
	2.990	"	0.2030		2.990	"	0.2030
	3.350	"	0.2135		3.350	"	0.2135

Table 1

0.01 0.01 0.01 = 0.01

0.01 0.01 0.01 = 0.01

0.01 0.01 0.01 = 0.01

0.01 0.01 0.01 = 0.01

$\lambda$	$\lambda^2$	$\lambda^3$
0.010.0	0.0001	0.000001
0.020.0	0.0004	0.000008
0.030.0	0.0009	0.000027
0.040.0	0.0016	0.000064
0.050.0	0.0025	0.000125
0.060.0	0.0036	0.000216
0.070.0	0.0049	0.000343
0.080.0	0.0064	0.000512
0.090.0	0.0081	0.000729
0.100.0	0.0100	0.001000
0.110.0	0.0121	0.001331
0.120.0	0.0144	0.001728
0.130.0	0.0169	0.002197
0.140.0	0.0196	0.002744
0.150.0	0.0225	0.003375
0.160.0	0.0256	0.004096
0.170.0	0.0289	0.004913
0.180.0	0.0324	0.005832
0.190.0	0.0361	0.006859
0.200.0	0.0400	0.008000

Table 2

0.01 0.01 0.01 = 0.01

0.01 0.01 0.01 = 0.01

0.01 0.01 0.01 = 0.01

0.01 0.01 0.01 = 0.01

$\lambda$	$\lambda^2$	$\lambda^3$
0.210.0	0.0441	0.009261
0.220.0	0.0484	0.011264
0.230.0	0.0529	0.013667
0.240.0	0.0576	0.016464
0.250.0	0.0625	0.019687
0.260.0	0.0676	0.023328
0.270.0	0.0729	0.027407
0.280.0	0.0784	0.031936
0.290.0	0.0841	0.036913
0.300.0	0.0900	0.042400
0.310.0	0.0961	0.048391
0.320.0	0.1024	0.054888
0.330.0	0.1089	0.061893
0.340.0	0.1156	0.069408
0.350.0	0.1225	0.077435
0.360.0	0.1296	0.085976
0.370.0	0.1369	0.095033
0.380.0	0.1444	0.104608
0.390.0	0.1521	0.114703
0.400.0	0.1600	0.125312
0.410.0	0.1681	0.136439
0.420.0	0.1764	0.148088
0.430.0	0.1849	0.160263
0.440.0	0.1936	0.172968
0.450.0	0.2025	0.186197
0.460.0	0.2116	0.199956
0.470.0	0.2209	0.214249
0.480.0	0.2304	0.229080
0.490.0	0.2401	0.244453
0.500.0	0.2500	0.260375

## SPECIMEN NO.15

Run No.1

$$F_N = 201.29 \text{ lb.}$$

$$F_N = 91.3 \text{ kg}$$

$$S_N = 13360 \text{ psi}$$

$$s_n = 939 \text{ kg/cm}^2$$

$Q_A$	$s_t$	$\phi_R$	$\theta_R$	$f$
120	12.6	- - -	- - -	0.0123
240	25.2	- - -	- - -	0.0246
360	37.8	0.069	$5.42 \times 10^{-6}$	0.0368
480	50.5	- - -	- - -	0.0491
600	63.1	0.161	12.90 "	0.0614
720	75.6	0.011	0.90 "	0.0736
840	88.4	0.057	4.50 "	0.0860
960	101.0	0.034	2.68 "	0.0982
1080	113.6	0.069	5.42 "	0.1104
1200	126.1	0.126	9.95 "	0.1226
1320	138.9	0.252	19.90 "	0.1350
1440	151.2	0.355	28.00 "	0.1472
1560	164.0	0.458	36.20 "	0.1595
1680	176.6	0.653	51.55 "	0.1716
1800	189.0	0.734	57.90 "	0.1840

Material: Copper

Surface Finish: 4/0 paper



SECTION NO. 12

DATE 1911

$P = 201.29 \text{ lb.}$

$Y_H = 21.3 \text{ in.}$

$Z_H = 13300 \text{ in.}^3$

$F = 255 \text{ lb./in.}^2$

Y	X	Z	A	F
120	—	—	24.2	—
130	—	—	25.2	—
140	—	—	27.8	0.049
150	—	—	28.2	—
160	—	—	31.1	0.181
170	—	—	32.8	0.201
180	—	—	33.2	0.207
190	—	—	34.2	0.208
200	—	—	34.2	0.208
210	—	—	34.2	0.208
220	—	—	34.2	0.208
230	—	—	34.2	0.208
240	—	—	34.2	0.208
250	—	—	34.2	0.208
260	—	—	34.2	0.208
270	—	—	34.2	0.208
280	—	—	34.2	0.208
290	—	—	34.2	0.208
300	—	—	34.2	0.208
310	—	—	34.2	0.208
320	—	—	34.2	0.208
330	—	—	34.2	0.208
340	—	—	34.2	0.208
350	—	—	34.2	0.208
360	—	—	34.2	0.208
370	—	—	34.2	0.208
380	—	—	34.2	0.208
390	—	—	34.2	0.208
400	—	—	34.2	0.208

Material: Copper  
Surface Finish: 4/0 paper

## SPECIMEN NO.15 (continued)

Run No.2 $P_N = 168.16 \text{ lb.}$  $P_N = 76.4 \text{ kg}$  $\Delta_N = 11170 \text{ psi}$  $s_N = 785 \text{ kg/cm}^2$ 

$Q_A$	$\psi_R$	$\theta_R$	$r$
120	- - -	- - -	0.0147
240	0.011	$0.90 \times 10^{-6}$	0.0294
360	0.023	1.81 "	0.0441
480	- - -	- - -	0.0588
600	0.011	0.90 "	0.0735
720	0.034	2.68 "	0.0882
840	0.034	2.68 "	0.1028
960	0.069	5.42 "	0.1175
1080	0.103	8.15 "	0.1320
1200	0.194	15.30 "	0.1470
1320	0.218	17.20 "	0.1615
1440	0.229	18.09 "	0.1762
1560	0.309	24.40 "	0.1910
1680	0.619	48.85 "	0.2060
1800	- - -	- - -	0.2203

Run No.3 $P_N = 117.41 \text{ lb.}$  $P_N = 53.3 \text{ kg}$  $\Delta_N = 7800 \text{ psi}$  $s_N = 548 \text{ kg/cm}^2$ 

$Q_A$	$\psi_R$	$\theta_R$	$r$
120	- - -	- - -	0.0211
240	- - -	- - -	0.0421
360	- - -	- - -	0.0632
480	0.023	$1.81 \times 10^{-6}$	0.0842
600	0.126	9.95 "	0.1052
720	0.149	11.76 "	0.1265
840	0.229	18.09 "	0.1475
960	- - -	- - -	0.1686

Year	Age	Sex	Weight (lb)	Length (in)	Wing (in)	Tail (in)	Bill (in)	Foot (in)	Middle toe (in)	Claw (in)	Weight (lb)	Length (in)	Wing (in)	Tail (in)	Bill (in)	Foot (in)	Middle toe (in)	Claw (in)
1900	10	♂	10.0	18.0	10.0	12.0	1.0	1.0	1.0	1.0	10.0	18.0	10.0	12.0	1.0	1.0	1.0	1.0
1901	11	♂	11.0	19.0	11.0	13.0	1.1	1.1	1.1	1.1	11.0	19.0	11.0	13.0	1.1	1.1	1.1	1.1
1902	12	♂	12.0	20.0	12.0	14.0	1.2	1.2	1.2	1.2	12.0	20.0	12.0	14.0	1.2	1.2	1.2	1.2
1903	13	♂	13.0	21.0	13.0	15.0	1.3	1.3	1.3	1.3	13.0	21.0	13.0	15.0	1.3	1.3	1.3	1.3
1904	14	♂	14.0	22.0	14.0	16.0	1.4	1.4	1.4	1.4	14.0	22.0	14.0	16.0	1.4	1.4	1.4	1.4
1905	15	♂	15.0	23.0	15.0	17.0	1.5	1.5	1.5	1.5	15.0	23.0	15.0	17.0	1.5	1.5	1.5	1.5
1906	16	♂	16.0	24.0	16.0	18.0	1.6	1.6	1.6	1.6	16.0	24.0	16.0	18.0	1.6	1.6	1.6	1.6
1907	17	♂	17.0	25.0	17.0	19.0	1.7	1.7	1.7	1.7	17.0	25.0	17.0	19.0	1.7	1.7	1.7	1.7
1908	18	♂	18.0	26.0	18.0	20.0	1.8	1.8	1.8	1.8	18.0	26.0	18.0	20.0	1.8	1.8	1.8	1.8
1909	19	♂	19.0	27.0	19.0	21.0	1.9	1.9	1.9	1.9	19.0	27.0	19.0	21.0	1.9	1.9	1.9	1.9
1910	20	♂	20.0	28.0	20.0	22.0	2.0	2.0	2.0	2.0	20.0	28.0	20.0	22.0	2.0	2.0	2.0	2.0

## SPECIMEN NO.15 (continued)

Run No.4

$$F_N = 168.16 \text{ lb.}$$

$$F_N = 76.4 \text{ kg}$$

$$S_N = 11170 \text{ psi}$$

$$s_n = 785 \text{ kg/cm}^2$$

$C_A$	$\psi_R$	$\theta_R$	$f$
120	- - -	- - -	0.0147
240	0.103	$8.15 \times 10^{-6}$	0.0294
360	0.149	11.76 "	0.0441
480	0.195	15.40 "	0.0588
600	0.344	27.15 "	0.0735
720	0.413	32.60 "	0.0882
840	0.768	60.65 "	0.1028
960	1.134	89.50 "	0.1175
1080	- - -	- - -	0.1320



1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023, 2024, 2025, 2026, 2027, 2028, 2029, 2030, 2031, 2032, 2033, 2034, 2035, 2036, 2037, 2038, 2039, 2040, 2041, 2042, 2043, 2044, 2045, 2046, 2047, 2048, 2049, 2050, 2051, 2052, 2053, 2054, 2055, 2056, 2057, 2058, 2059, 2060, 2061, 2062, 2063, 2064, 2065, 2066, 2067, 2068, 2069, 2070, 2071, 2072, 2073, 2074, 2075, 2076, 2077, 2078, 2079, 2080, 2081, 2082, 2083, 2084, 2085, 2086, 2087, 2088, 2089, 2090, 2091, 2092, 2093, 2094, 2095, 2096, 2097, 2098, 2099, 2100, 2101, 2102, 2103, 2104, 2105, 2106, 2107, 2108, 2109, 2110, 2111, 2112, 2113, 2114, 2115, 2116, 2117, 2118, 2119, 2120, 2121, 2122, 2123, 2124, 2125, 2126, 2127, 2128, 2129, 2130, 2131, 2132, 2133, 2134, 2135, 2136, 2137, 2138, 2139, 2140, 2141, 2142, 2143, 2144, 2145, 2146, 2147, 2148, 2149, 2150, 2151, 2152, 2153, 2154, 2155, 2156, 2157, 2158, 2159, 2160, 2161, 2162, 2163, 2164, 2165, 2166, 2167, 2168, 2169, 2170, 2171, 2172, 2173, 2174, 2175, 2176, 2177, 2178, 2179, 2180, 2181, 2182, 2183, 2184, 2185, 2186, 2187, 2188, 2189, 2190, 2191, 2192, 2193, 2194, 2195, 2196, 2197, 2198, 2199, 2200, 2201, 2202, 2203, 2204, 2205, 2206, 2207, 2208, 2209, 2210, 2211, 2212, 2213, 2214, 2215, 2216, 2217, 2218, 2219, 2220, 2221, 2222, 2223, 2224, 2225, 2226, 2227, 2228, 2229, 2230, 2231, 2232, 2233, 2234, 2235, 2236, 2237, 2238, 2239, 2240, 2241, 2242, 2243, 2244, 2245, 2246, 2247, 2248, 2249, 2250, 2251, 2252, 2253, 2254, 2255, 2256, 2257, 2258, 2259, 2260, 2261, 2262, 2263, 2264, 2265, 2266, 2267, 2268, 2269, 2270, 2271, 2272, 2273, 2274, 2275, 2276, 2277, 2278, 2279, 2280, 2281, 2282, 2283, 2284, 2285, 2286, 2287, 2288, 2289, 2290, 2291, 2292, 2293, 2294, 2295, 2296, 2297, 2298, 2299, 2300, 2301, 2302, 2303, 2304, 2305, 2306, 2307, 2308, 2309, 2310, 2311, 2312, 2313, 2314, 2315, 2316, 2317, 2318, 2319, 2320, 2321, 2322, 2323, 2324, 2325, 2326, 2327, 2328, 2329, 2330, 2331, 2332, 2333, 2334, 2335, 2336, 2337, 2338, 2339, 2340, 2341, 2342, 2343, 2344, 2345, 2346, 2347, 2348, 2349, 2350, 2351, 2352, 2353, 2354, 2355, 2356, 2357, 2358, 2359, 2360, 2361, 2362, 2363, 2364, 2365, 2366, 2367, 2368, 2369, 2370, 2371, 2372, 2373, 2374, 2375, 2376, 2377, 2378, 2379, 2380, 2381, 2382, 2383, 2384, 2385, 2386, 2387, 2388, 2389, 2390, 2391, 2392, 2393, 2394, 2395, 2396, 2397, 2398, 2399, 2400, 2401, 2402, 2403, 2404, 2405, 2406, 2407, 2408, 2409, 2410, 2411, 2412, 2413, 2414, 2415, 2416, 2417, 2418, 2419, 2420, 2421, 2422, 2423, 2424, 2425, 2426, 2427, 2428, 2429, 2430, 2431, 2432, 2433, 2434, 2435, 2436, 2437, 2438, 2439, 2440, 2441, 2442, 2443, 2444, 2445, 2446, 2447, 2448, 2449, 2450, 2451, 2452, 2453, 2454, 2455, 2456, 2457, 2458, 2459, 2460, 2461, 2462, 2463, 2464, 2465, 2466, 2467, 2468, 2469, 2470, 2471, 2472, 2473, 2474, 2475, 2476, 2477, 2478, 2479, 2480, 2481, 2482, 2483, 2484, 2485, 2486, 2487, 2488, 2489, 2490, 2491, 2492, 2493, 2494, 2495, 2496, 2497, 2498, 2499, 2500, 2501, 2502, 2503, 2504, 2505, 2506, 2507, 2508, 2509, 2510, 2511, 2512, 2513, 2514, 2515, 2516, 2517, 2518, 2519, 2520, 2521, 2522, 2523, 2524, 2525, 2526, 2527, 2528, 2529, 2530, 2531, 2532, 2533, 2534, 2535, 2536, 2537, 2538, 2539, 2540, 2541, 2542, 2543, 2544, 2545, 2546, 2547, 2548, 2549, 2550, 2551, 2552, 2553, 2554, 2555, 2556, 2557, 2558, 2559, 2560, 2561, 2562, 2563, 2564, 2565, 2566, 2567, 2568, 2569, 2570, 2571, 2572, 2573, 2574, 2575, 2576, 2577, 2578, 2579, 2580, 2581, 2582, 2583, 2584, 2585, 2586, 2587, 2588, 2589, 2590, 2591, 2592, 2593, 2594, 2595, 2596, 2597, 2598, 2599, 2600, 2601, 2602, 2603, 2604, 2605, 2606, 2607, 2608, 2609, 2610, 2611, 2612, 2613, 2614, 2615, 2616, 2617, 2618, 2619, 2620, 2621, 2622, 2623, 2624, 2625, 2626, 2627, 2628, 2629, 2630, 2631, 2632, 2633, 2634, 2635, 2636, 2637, 2638, 2639, 2640, 2641, 2642, 2643, 2644, 2645, 2646, 2647, 2648, 2649, 2650, 2651, 2652, 2653, 2654, 2655, 2656, 2657, 2658, 2659, 2660, 2661, 2662, 2663, 2664, 2665, 2666, 2667, 2668, 2669, 2670, 2671, 2672, 2673, 2674, 2675, 2676, 2677, 2678, 2679, 26

1997

$\lambda$	$\mu$	$\nu$	$\alpha^2$
1.00000	—	—	0.01
1.00000	—	0.010	0.02
1.00000	—	0.020	0.03
1.00000	—	0.030	0.04
1.00000	—	0.040	0.05
1.00000	—	0.050	0.06
1.00000	—	0.060	0.07
1.00000	—	0.070	0.08
1.00000	—	0.080	0.09
1.00000	—	0.090	0.10

SPECIMEN NO.15 (continued)

Run No.5

$P_H = 117.41 \text{ lb.}$   
 $P_H = 53.3 \text{ kg}$   
 $S_H = 7800 \text{ psi}$   
 $s_n = 548 \text{ kg/cm}^2$

$Q_A$	$\phi_R$	$\theta_R$	$f$
120	0.080	$6.34 \times 10^{-6}$	0.0211
240	0.321	25.30	0.0421
360	0.596	47.10	0.0632
480	1.396	110.0	0.0842
600	- - -	- - -	0.1052

Run No.7

$P_H = 64.78 \text{ lb.}$   
 $P_H = 29.4 \text{ kg}$   
 $S_H = 4300 \text{ psi}$   
 $s_n = 302 \text{ kg/cm}^2$

$\phi_R$	$\theta_R$	$f$
0.092	$7.24 \times 10^{-6}$	0.0382
0.241	19.04	0.0763
0.940	74.20	0.1144
8.50	671.0	0.1526

1. Summary of Results

Table 1

of the data

of the data

of the data

of the data

$\theta$	$\theta$	$\theta$
0.00	0.00	0.00
0.01	0.01	0.01
0.02	0.02	0.02
0.03	0.03	0.03
0.04	0.04	0.04
0.05	0.05	0.05
0.06	0.06	0.06
0.07	0.07	0.07
0.08	0.08	0.08
0.09	0.09	0.09
0.10	0.10	0.10

Table 2

of the data

of the data

of the data

of the data

$\theta$	$\theta$	$\theta$
0.00	0.00	0.00
0.01	0.01	0.01
0.02	0.02	0.02
0.03	0.03	0.03
0.04	0.04	0.04
0.05	0.05	0.05
0.06	0.06	0.06
0.07	0.07	0.07
0.08	0.08	0.08
0.09	0.09	0.09
0.10	0.10	0.10

## SPECIMEN NO.16

Material: 2S Aluminum

Surface Finish: No. 1 Paper

Run No.1

$$F_N = 764 \text{ kg}$$

$$s_n = 772 \text{ kg/cm}^2$$

$Q_A$	$s_t$	$\psi_R$	$\theta_R$	$f$	$\psi_o$
12	1.24	0.458	$30.10 \times 10^{-6}$	0.0015	0.183
30	3.11	0.138	10.87 "	0.0037	0.413
60	6.23	0.138	10.87 "	0.0073	0.836
90	9.33	0.275	21.65 "	0.0119	1.064
120	12.43	0.321	25.30 "	0.0147	1.443
150	15.55	0.424	33.40 "	0.0183	1.866
180	18.65	0.596	47.00 "	0.0220	2.085
210	21.80	0.699	55.10 "	0.0256	2.462
240	24.90	0.630	49.65 "	0.0293	2.820
270	28.00	0.722	57.00 "	0.0330	3.130
300	31.15	0.756	59.60 "	0.0367	3.450
330	34.25	0.814	64.15 "	0.0403	3.930
360	37.35	0.836	65.95 "	0.0440	4.220
390	40.50	0.956	75.40 "	0.0476	4.530
420	43.65	0.985	77.60 "	0.0514	4.810



Surface Finish: No. 1 Paper

$$\sigma = 772 \text{ kg/cm}^2$$

$$\tau = 764 \text{ kg}$$

$\sigma$	$\tau$	$\sigma$	$\tau$	$\sigma$	$\tau$
12	1.24	0.452	30.10	0.0015	0.183
30	3.11	0.138	10.87	0.0037	0.413
60	6.23	0.138	10.87	0.0073	0.836
90	9.35	0.138	10.87	0.0110	1.259
120	12.47	0.138	10.87	0.0147	1.682
150	15.59	0.424	33.40	0.0183	2.105
180	18.72	0.296	47.00	0.0220	2.528
210	21.84	0.669	55.10	0.0256	2.951
240	24.97	0.669	55.10	0.0293	3.374
270	28.00	0.723	57.60	0.0330	3.797
300	31.13	0.723	57.60	0.0367	4.220
330	34.25	0.723	57.60	0.0404	4.643
360	37.38	0.723	57.60	0.0441	5.066
390	40.50	0.982	77.60	0.0478	5.489
420	43.63	0.982	77.60	0.0515	5.912

## SPECIMEN NO.16 (continued)

Material: 2S Aluminum

Surface Finish: No. 1 Paper

Run No.2

$$F_N = 91.3 \text{ kg}$$

$$s_n = 928 \text{ kg/cm}^2$$

$Q_A$	$s_t$	$\psi_R$	$\theta_R$	$f$	$\psi_o$
12	1.24	- - -	- - -	0.0012	- - -
30	3.11	- - -	- - -	0.0031	0.378
60	6.23	- - -	- - -	0.0061	0.596
90	9.33	0.114	$9.00 \times 10^{-6}$	0.0092	1.030
120	12.43	0.138	10.87 "	0.0123	1.283
150	15.55	0.183	14.42 "	0.0153	1.640
180	18.65	0.138	10.87 "	0.0184	1.970
210	21.80	0.206	16.24 "	0.0214	2.220
240	24.90	0.252	19.86 "	0.0245	2.625
270	28.00	0.283	22.30 "	0.0276	2.980
300	31.15	0.367	28.90 "	0.0307	3.240
330	34.25				

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APPENDIX C  
SAMPLE CALCULATIONS



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APPENDIX B  
 PHYSICAL PROPERTIES

TEMPERATURE, °C	DENSITY, g/cm <sup>3</sup>	REFRACTIVE INDEX, n <sub>D</sub>	WAVELENGTH, μm
20	1.017	1.332	0.6563
25	1.016	1.331	0.6563
30	1.015	1.330	0.6563
35	1.014	1.329	0.6563
40	1.013	1.328	0.6563
45	1.012	1.327	0.6563
50	1.011	1.326	0.6563
55	1.010	1.325	0.6563
60	1.009	1.324	0.6563
65	1.008	1.323	0.6563
70	1.007	1.322	0.6563
75	1.006	1.321	0.6563
80	1.005	1.320	0.6563
85	1.004	1.319	0.6563
90	1.003	1.318	0.6563
95	1.002	1.317	0.6563
100	1.001	1.316	0.6563

SAMPLE CALCULATIONS

Calculated angle of twist of specimen without interface =  $\psi_o$

$$\psi = \frac{T_A L}{E_s J} \text{ radians} \quad (1)$$

$$J = \frac{\pi(D_o^4 - D_i^4)}{32} \quad (2)$$

$$\psi_c = \frac{180}{\pi} \times 60 \times \psi \quad (3)$$

$$T_A = 2.205 \times 10^{-3} Q_A \quad (4)$$

Substituting (2), (3), and (4) in (1) gives

$$\psi_c = \frac{77.3 \times Q_A \times L}{(D_o^4 - D_i^4) \times E_s} \text{ Min.arc.} \quad (5)$$

Maximum tangential stress =  $S_T$ .

$$S_T = \frac{16 T_A D_o}{\pi(D_o^4 - D_i^4)} \quad (6)$$

Substituting (4) in (6) gives

$$S_T = 1.121 \times 10^{-2} \frac{D_o}{D_o^4 - D_i^4} \times Q \text{ psi} \quad (7)$$

Observed angle of twist of specimen =  $\psi_o$ .

With 10 x objective calibration with micrometer stage shows one drum unit of optical micrometer represents 0.00004101° on indicator.

# EXPERIMENTAL RESULTS

Calculated value of angle of twist of specimen without

disturbance =  $\phi_0$

$$(1) \quad \phi = \frac{1}{2} \left( \frac{\tau}{G} \right) \left( \frac{L}{r} \right) \quad \text{without } \frac{\tau}{G} \text{ variation}$$

$$(2) \quad \phi = \frac{1}{2} \left( \frac{\tau}{G} \right) \left( \frac{L}{r} \right) \left( \frac{1}{1 - \frac{\tau}{G} \frac{L}{r}} \right)$$

$$(3) \quad \phi_0 = \frac{100}{2} \times 60 \times \frac{1}{2} = 1500$$

$$(4) \quad T_A = 2.502 \times 10^{-3} \times 10^3$$

Investigating (2), (3), and (4) in (1) gives

$$(5) \quad \phi = \frac{1500}{\left( \frac{100}{2} - \frac{100}{2} \right) \times 10^3} \times 10^3$$

Calculated value of angle =  $\phi_0$

$$(6) \quad \phi = \frac{1500}{\left( \frac{100}{2} - \frac{100}{2} \right) \times 10^3}$$

Investigating (1) in (1) gives

$$(7) \quad \phi = 1.191 \times 10^{-3} \times 10^3 = 1.191$$

Observed angle of twist of specimen =  $\phi_0$

It is a specimen subjected with disturbance

There are some cases of angles measured respectively

at different points

$\phi_s$  drum units = 0.00004101 x  $\phi_s$  inches on indicator.

$$\phi_o = \frac{\phi_s}{R} \text{ radians} \times \frac{180}{\pi} \frac{\text{degrees}}{\text{radians}} \times 60 \frac{\text{min.}}{\text{degree}} .$$

$$\phi_o = \frac{\phi_s (0.00004101)}{12.33} \times 3440$$

$$\phi_o = 0.01144 \phi_s \quad (8)$$

Coefficient of friction =  $f$ .

$$T = \frac{1}{3} f \times F_N \frac{(D_o^3 - D_1^3)}{(D_o^2 - D_1^2)} \quad (9)$$

$T$  = torque of friction about axis of shaft.

Substituting (4) in (9) gives

$$f = \frac{Q_A}{F_N} \times 6.615 \times 10^{-3} \times \frac{(D_o^2 - D_1^2)}{(D_o^3 - D_1^3)}$$



Let  $\phi$  be a function on  $\mathbb{R}^n$  such that  $\phi(x) = 0$  for  $|x| \geq 1$ .

$$\frac{1}{2} \int_{\mathbb{R}^n} |\nabla \phi|^2 dx = \int_{\mathbb{R}^n} \phi \Delta \phi dx = 0$$

$$\frac{1}{2} \int_{\mathbb{R}^n} |\nabla \phi|^2 dx = \int_{\mathbb{R}^n} \phi \Delta \phi dx = 0$$

(14)  $\int_{\mathbb{R}^n} |\nabla \phi|^2 dx = 0$

Consequently  $\phi = 0$ .

(15)  $\frac{1}{2} \int_{\mathbb{R}^n} |\nabla \phi|^2 dx = \int_{\mathbb{R}^n} \phi \Delta \phi dx = 0$

$\phi$  is a function on  $\mathbb{R}^n$  such that  $\phi(x) = 0$  for  $|x| \geq 1$ .

Consequently  $\phi = 0$ .

$$\frac{1}{2} \int_{\mathbb{R}^n} |\nabla \phi|^2 dx = \int_{\mathbb{R}^n} \phi \Delta \phi dx = 0$$

Consequently  $\phi = 0$ .

$$\frac{1}{2} \int_{\mathbb{R}^n} |\nabla \phi|^2 dx = \int_{\mathbb{R}^n} \phi \Delta \phi dx = 0$$

Consequently  $\phi = 0$ .

$$\frac{1}{2} \int_{\mathbb{R}^n} |\nabla \phi|^2 dx = \int_{\mathbb{R}^n} \phi \Delta \phi dx = 0$$

Consequently  $\phi = 0$ .

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APPENDIX D  
SUPPLEMENTARY DISCUSSION

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### SUPPLEMENTARY DISCUSSION

In the discussion of results, it was suggested that yield effects in the metal of the interfaces contributed to the small initial deformations. An examination of one of the test runs for this effect is therefore in order.

Referring to Figure XIV, let us examine the stress situation in the C-1018 steel specimen for one of the initial deformations.

The maximum combined shearing stress in a cylinder loaded in this manner is given as follows:  $(S_s)_{\max} = \sqrt{\frac{1}{4}(S_H)^2 + (S_T)^2}$   
For  $S_H$  and  $S_T$  values, respectively, of 13200 and 1420 psi, the  $(S_s)_{\max}$  is equal to 6750 psi.

Maximum shear theory states that yielding will occur when  $(S_s)_{\max}$  equals the maximum shearing stress at yield point obtained from a tension test. The maximum shearing stress at yield point is one half yield stress for a tensile specimen.

Ayerson Steel Specifications for C-1018 steel give a yield value of 48000 psi.

Therefore maximum shear stress at yield point equals 24000 psi. The calculated stress for the specimen is well below this value; therefore yield will not occur in the bulk metal.

The normal stress value used in computing the combined shear stress was determined by using the cross-section area of the specimen, which at the interface is the apparent area of





contact. The real area of contact is less than this value due to the asperities in the metal of the interface.

Bowden and Tabor<sup>(4)</sup> give the following relation for real area of contact:

$$A_r = \frac{F}{P_m}$$

$P_m$  = mean pressure over area of contact

$$P_m = C \times S_{\text{yield}}$$

C has a value of 3 for material and surface finish used here.

$$P_m = 144000 \text{ psi for this case.}$$

$$A_{\text{real}} = 0.0014 \text{ in}^2, \text{ which is considerably less than the apparent value of } 0.0153 \text{ in}^2.$$

This would give a maximum combined shear stress in the contact surface considerably in excess of that required to initiate yield in the metal.

It is thus apparent that the stresses at the contact surface are more than sufficient to insure yield in the asperities in the metal interface. For very small values of deformation, the yield effects may thus be the sole contributing factor.

Now consider the stress values for the specimen under conditions encountered just prior to the advent of free sliding to  $S_N$  and  $S_T$  of 13260 and 4960 psi. The  $(S_s)_{\text{max}}$  value is 8260 psi. Thus it is apparent that yield in the bulk material of the specimen does not occur, and all but the smallest displacements are due to slip between the two contact surfaces.

contact. The real area of contact is less than this value  
due to the deformation in the metal of the indenter.

From the above, the following relation can be derived

area of contact

$$A = \frac{F}{p}$$

$p$  = mean pressure over area of contact

$$p = C \times \sqrt[3]{F}$$

$C$  has a value of 1 for material and surface finish  
used here.

Substituting the values

$$A_{real} = 0.004 \text{ in}^2 \text{ which is considerably less than the apparent value of } 0.015 \text{ in}^2.$$

This would give a maximum combined shear stress in the contact  
surface considerably in excess of that required to initiate  
slip in the metal.

It is thus apparent that the stresses in the contact  
surface are well above sufficient to insure slip in the upper  
plate in the metal interface. But very small values of shear  
stress in the plate suffice to give the only explanation  
for the results.

The maximum shear stress in the specimen under  
conditions considered just prior to the onset of shear sliding  
is  $\frac{1}{2} \sigma_y$  or  $\frac{1}{2} \times 10,000$  psi. The  $\frac{1}{2} \sigma_y$  value is  
3500 psi. This is in agreement with plate in the metal interface  
of the specimen from one corner, and all the smaller values  
elsewhere are due to slip between the two contact surfaces.

APPENDIX E  
ORIGINAL DATA





# SPECIMEN NO.1

Material: C-1018 Steel

Control Specimen (without interface)

	<u>Run No.1</u>	<u>Run No.2</u>	<u>Run No.3</u>	<u>Run No.4</u>	<u>Run No.5</u>
	$F_N = 150 \text{ lb.}$	$F_N = 190.7 \text{ lb.}$	$F_N = 225.4 \text{ lb.}$	$F_N = 74.9 \text{ lb.}$	$F_N = 111.9 \text{ lb.}$
$Q_A$	$\psi_B$	$\psi_B$	$\psi_B$	$\psi_B$	$\psi_B$
150	44	44	49	40	45
300	92	89	96	101	97
450	139	143	146	-	144
600	189	197	193	-	196
750	239	243	-	-	-
900	285	296	292	-	-
1050	332	-	342	-	-
1200	-	-	391	-	-
1350	-	-	-	-	-

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## SPECIMEN NO.2

Material: C-1018 Steel

Surface Finish:  
As machined (lathe)Run No.1 $P_N = 251.2 \text{ lb.}$ 

$Q_A$	$\psi_S$
120	31
240	60
360	103
480	145
600	187
720	227
840	266
900	282
960	300
1080	342
1200	384
1320	433
1440	478

## SPECIMEN NO.3

Material: C-1018 Steel

Surface Finish: No.1 Paper

Run No.2 $P_N = 200.3 \text{ lb.}$ 

$Q_A$	$\psi_S$
120	38
240	80
360	123
480	168
600	203
720	241
840	-
900	-

Run No.3 $P_N = 201.29 \text{ lb.}$ 

$Q_A$	$\psi_S$	$Q_A$	$\psi_{SR}$	$\psi_{SR}$
120	36	120	--	30
240	74	240	--	40
360	110	360	--	50
480	144	480	--	56
600	183.5	600	--	70
720	226	720	5	82
840	268	840	7	97
900	-	900	--	124
		960	17	125
		1080	16	156
		1200	18	254
		1320	20	257
		1440	28	270
		1560	30	319
		1680	31	-



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James I. Taylor, Jr.

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## SPECIMEN NO.3 (continued)

<u>Run No.3 (cont.)</u>		<u>Run No.4</u>		<u>Run No.5</u>		<u>Run No.6</u>	
$F_N = 201.29 \text{ lb.}$		$F_N = 168.16 \text{ lb.}$		$F_N = 117.41 \text{ lb.}$		$F_N = 64.78 \text{ lb.}$	
$Q_A$	$\psi_{SR}$	$Q_A$	$\psi_{SR}$	$Q_A$	$\psi_{SR}$	$Q_A$	$\psi_{SR}$
2520	97	120	--	120	--	120	--
2640	124	240	--	240	15	240	--
2760	125	360	--	360	16	360	5
2880	156	480	--	480	13	480	16
3000	254	600	--	600	24	600	19
3120	257	720	2	720	19	720	317
3240	270	840	5	840	28	840	--
3360	319	960	8	960	29		
3480	--	1080	7	1080	29		
		1200	7	1200	41		
		1320	30	1320	58		
		1440	30	1440	75		
		1560	28	1560	109		
		1680	41	1680	--		
		1800	58				
		1920	67				
		2040	78				
		2160	142				
		2280	214				
		2400	--				

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# SPECIMEN NO.4

Material: C-1018 Steel

Surface Finish: 2/o Paper

	<u>Run No.1</u>	<u>Run No.2</u>	<u>Run No.3</u>	<u>Run No.4</u>	<u>Run No.5</u>	<u>Run No.6</u>
	$F_N = 81.75 \text{ lb.}$	$F_N = 116.3 \text{ lb.}$	$F_N = 167 \text{ lb.}$	$F_N = 200.3 \text{ lb.}$	$F_N = 200.3 \text{ lb.}$	$F_N = 251.2 \text{ lb.}$
$Q_A$	$\psi_s$	$\psi_s$	$\psi_s$	$\psi_s$	$\psi_s$	$\psi_s$
120	54	34	39	46	32	33
240	115	83	72	71	68	75
300	--	--	--	83	--	--
360		114	108	--	105	107
420		--	--	114	--	--
480			146	--	145	149
600			192	182	180	186
720			231	220	218	226
840			279	--	258	266
900			--	273	--	--
960				--	294	308
1020				320	--	--
1080				--	336	349
1140				372	--	--
1200				--	373	379
1320					413	416
1440					--	--



$\lambda = 87.12 \text{ } \mu\text{m}$      $\lambda = 172.3 \text{ } \mu\text{m}$      $\lambda = 193 \text{ } \mu\text{m}$      $\lambda = 300.3 \text{ } \mu\text{m}$      $\lambda = 300.3 \text{ } \mu\text{m}$

TRAIL OF A HINDU GODDESS

## SPECIMEN NO.5

Material: C-1018 Steel

Surface Finish: 4/o paper

<u>Run No.1</u>		<u>Run No.2</u>		<u>Run No.3</u>		<u>Run No.4</u>	
$F_N = 116.3 \text{ lb.}$		$F_N = 167 \text{ lb.}$		$F_N = 200.2 \text{ lb.}$		$F_N = 251.2 \text{ lb.}$	
$Q_A$	$\psi_s$	$Q_A$	$\psi_s$	$Q_A$	$\psi_s$	$Q_A$	$\psi_s$
120	33	120	39	120	30	120	--
150	--	150	--	150	--	150	43
240	73	240	82	240	74	240	--
300	--	300	--	300	--	300	91
360	108	360	126	360	117	360	--
420	--	420	--	420	--	420	--
450	--	450	--	450	--	450	141
480	153	480	167	480	151	480	--
600	188	600	201	600	191	600	190
720	228	720	232	720	230	720	--
750	--	750	--	750	--	750	241
840	318	840	280	840	269	840	--
900	--	900	--	900	--	900	291
960	--	960	321	960	310	960	--
		1020	--	1020	--	1020	--
		1050	--	1050	--	1050	332
		1080	385	1080	351	1080	--
		1140	--	1140	--	1140	--
				1200	390	1200	393
				1320	430	1320	--
				1350	--	1350	438
						1440	--
						1500	492
						1560	--

100-200-3 : 100-200-3

Year	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100
1900	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100	

SPECIMEN NO.5 (continued)

90

<u>Run No.5</u>		<u>Run No.6</u>		<u>Run No.7</u>	
$F_N = 168.2 \text{ lb.}$		$F_N = 117.41 \text{ lb.}$		$F_N = 64.78 \text{ lb.}$	
$Q_A$	$\psi_{SR}$		$\psi_{SR}$		$\psi_{SR}$
120	--		--		--
150	--		--		--
240	--		--		16
300	--		--		--
360	--		3		16
420	--		--		--
450	--		--		--
480	--		4		36
600	--		19		64
720	--		16		67
750	--		--		--
840	--		32		153
900	--		--		--
960	6		40		
1020	--		--		
1050	--		--		
1080	6		68		
1140	--		--		
1200	10		94		
1320	15		122		
1350	--		--		
1440	19		155		
1500	--		--		
1560	23				
1680	39				
1800	64				



# STATIONARY STATE

Run No. 1	Run No. 2	Run No. 3	Run No. 4
1000	1000	1000	1000
1001	1001	1001	1001
1002	1002	1002	1002
1003	1003	1003	1003
1004	1004	1004	1004
1005	1005	1005	1005
1006	1006	1006	1006
1007	1007	1007	1007
1008	1008	1008	1008
1009	1009	1009	1009
1010	1010	1010	1010
1011	1011	1011	1011
1012	1012	1012	1012
1013	1013	1013	1013
1014	1014	1014	1014
1015	1015	1015	1015
1016	1016	1016	1016
1017	1017	1017	1017
1018	1018	1018	1018
1019	1019	1019	1019
1020	1020	1020	1020
1021	1021	1021	1021
1022	1022	1022	1022
1023	1023	1023	1023
1024	1024	1024	1024
1025	1025	1025	1025
1026	1026	1026	1026
1027	1027	1027	1027
1028	1028	1028	1028
1029	1029	1029	1029
1030	1030	1030	1030
1031	1031	1031	1031
1032	1032	1032	1032
1033	1033	1033	1033
1034	1034	1034	1034
1035	1035	1035	1035
1036	1036	1036	1036
1037	1037	1037	1037
1038	1038	1038	1038
1039	1039	1039	1039
1040	1040	1040	1040
1041	1041	1041	1041
1042	1042	1042	1042
1043	1043	1043	1043
1044	1044	1044	1044
1045	1045	1045	1045
1046	1046	1046	1046
1047	1047	1047	1047
1048	1048	1048	1048
1049	1049	1049	1049
1050	1050	1050	1050
1051	1051	1051	1051
1052	1052	1052	1052
1053	1053	1053	1053
1054	1054	1054	1054
1055	1055	1055	1055
1056	1056	1056	1056
1057	1057	1057	1057
1058	1058	1058	1058
1059	1059	1059	1059
1060	1060	1060	1060
1061	1061	1061	1061
1062	1062	1062	1062
1063	1063	1063	1063
1064	1064	1064	1064
1065	1065	1065	1065
1066	1066	1066	1066
1067	1067	1067	1067
1068	1068	1068	1068
1069	1069	1069	1069
1070	1070	1070	1070
1071	1071	1071	1071
1072	1072	1072	1072
1073	1073	1073	1073
1074	1074	1074	1074
1075	1075	1075	1075
1076	1076	1076	1076
1077	1077	1077	1077
1078	1078	1078	1078
1079	1079	1079	1079
1080	1080	1080	1080
1081	1081	1081	1081
1082	1082	1082	1082
1083	1083	1083	1083
1084	1084	1084	1084
1085	1085	1085	1085
1086	1086	1086	1086
1087	1087	1087	1087
1088	1088	1088	1088
1089	1089	1089	1089
1090	1090	1090	1090
1091	1091	1091	1091
1092	1092	1092	1092
1093	1093	1093	1093
1094	1094	1094	1094
1095	1095	1095	1095
1096	1096	1096	1096
1097	1097	1097	1097
1098	1098	1098	1098
1099	1099	1099	1099
1100	1100	1100	1100

## SPECIMEN NO.6

Material: A-4140 Steel

Control Specimen (without interface)

<u>Run No.1</u>		<u>Run No.2</u>
$F_N = 251.2 \text{ lb.}$		$F_N = 200.2 \text{ lb.}$
$Q_A$	$\psi_s$	$\psi_s$
120	43	--
150	--	52
240	83	--
300	--	93
360	123	--
450	--	139
480	161	--
600	202	192
720	245	--
750	--	239
840	290	--
900	--	290
960	326	--
1020	--	
1080	363	
1200	400	

SECTION NO. 5

Material: A-4140 Steel

Control Specimen (without fillet)

Specimen No. 5		Specimen No. 5	
$P_u = 500.5 \text{ lb.}$		$P_u = 521.8 \text{ lb.}$	
4	120	4	120
--	150	13	150
25	240	--	240
--	300	83	300
83	360	--	360
--	420	133	420
133	480	--	480
--	540	181	540
181	600	305	600
305	660	348	660
--	720	--	720
348	780	--	780
--	840	380	840
380	900	--	900
--	960	380	960
--	1020	--	1020
--	1080	380	1080
--	1140	400	1140

SPECIMEN NO. 7

Material: A-4140 Steel

Surface Finish: As machined

	<u>Run No. 1</u>	<u>Run No. 2</u>	<u>Run No. 3</u>	<u>Run No. 4</u>
	$F_N = 116.3 \text{ lb.}$	$F_N = 167 \text{ lb.}$	$F_N = 200.2 \text{ lb.}$	$F_N = 251.2 \text{ lb.}$
$\psi_A$	$\psi_s$	$\psi_s$	$\psi_s$	$\psi_s$
120	32	38	38	42
150	--	--	--	51
240	74	78	--	--
300	--	--	108	119
360	123	130	--	--
450	--	--	--	--
480	169	187	--	--
600	219	236	214	211
720	--	294	270	--
750	--	--	--	--
840	--	--	--	--
900	--	--	356	344
960	--	--	--	--
1020	--	--	--	397



# THE KENTON

THE KENTON

THE KENTON

THE KENTON

THE KENTON

# SPECIMEN NO.8

Material: A-4140 Steel

Surface Finish: No.1 Paper

	<u>Run No.1</u>	<u>Run No.2</u>	<u>Run No.3</u>	<u>Run No.4</u>
	$F_N = 116.3 \text{ lb.}$	$F_N = 167 \text{ lb.}$	$F_N = 200.2 \text{ lb.}$	$F_N = 251.2 \text{ lb.}$
$Q_A$	$\psi_s$	$\psi_s$	$\psi_s$	$\psi_s$
150	54	59	48	51
300	111	116	109	109
450	165	168	178	161
600	241	223	220	219
750	284	277	276	287
900	--	--	339	340
1050			--	393



1020	1020	1020	1020	1020	1020
900	900	900	900	900	900
820	820	820	820	820	820
740	740	740	740	740	740
660	660	660	660	660	660
580	580	580	580	580	580
500	500	500	500	500	500
420	420	420	420	420	420
340	340	340	340	340	340
260	260	260	260	260	260
180	180	180	180	180	180
100	100	100	100	100	100

1020 1020 1020 1020 1020 1020  
900 900 900 900 900 900  
820 820 820 820 820 820  
740 740 740 740 740 740  
660 660 660 660 660 660  
580 580 580 580 580 580  
500 500 500 500 500 500  
420 420 420 420 420 420  
340 340 340 340 340 340  
260 260 260 260 260 260  
180 180 180 180 180 180  
100 100 100 100 100 100

1020 1020 1020 1020 1020 1020  
900 900 900 900 900 900  
820 820 820 820 820 820  
740 740 740 740 740 740  
660 660 660 660 660 660  
580 580 580 580 580 580  
500 500 500 500 500 500  
420 420 420 420 420 420  
340 340 340 340 340 340  
260 260 260 260 260 260  
180 180 180 180 180 180  
100 100 100 100 100 100

SPECIMEN NO.8 (continued)

Run No.5

Run No.6

Run No.7

$F_N = 200 \text{ lb.}$

$F_N = 167 \text{ lb.}$

$F_N = 201.29 \text{ lb.}$

$Q_A$	$\psi_s$	$\psi_s$	$Q_A$	$\psi_s$
150	59	49	120	--
300	111	122	240	--
450	160	186	360	--
600	220	219	480	--
750	--	280	600	--
900		--	720	--
			840	--
			960	1
			1080	4
			1200	5
			1320	8
			1440	8
			1560	12
			1680	22
			1800	36
			1920	70
			2040	75
			2160	132
			2280	232
			2400	--



(continued) 3.0M NMR 12-78

1.0M NMR 12-78		3.0M NMR 12-78		1.0M NMR 12-78	
$\delta$	Chemical Shift	$\delta$	Chemical Shift	$\delta$	Chemical Shift
—	1.50	—	1.50	—	1.50
—	1.55	—	1.55	—	1.55
—	1.60	—	1.60	—	1.60
—	1.65	—	1.65	—	1.65
—	1.70	—	1.70	—	1.70
—	1.75	—	1.75	—	1.75
—	1.80	—	1.80	—	1.80
—	1.85	—	1.85	—	1.85
—	1.90	—	1.90	—	1.90
—	1.95	—	1.95	—	1.95
—	2.00	—	2.00	—	2.00
—	2.05	—	2.05	—	2.05
—	2.10	—	2.10	—	2.10
—	2.15	—	2.15	—	2.15
—	2.20	—	2.20	—	2.20
—	2.25	—	2.25	—	2.25
—	2.30	—	2.30	—	2.30
—	2.35	—	2.35	—	2.35
—	2.40	—	2.40	—	2.40
—	2.45	—	2.45	—	2.45
—	2.50	—	2.50	—	2.50
—	2.55	—	2.55	—	2.55
—	2.60	—	2.60	—	2.60
—	2.65	—	2.65	—	2.65
—	2.70	—	2.70	—	2.70
—	2.75	—	2.75	—	2.75
—	2.80	—	2.80	—	2.80
—	2.85	—	2.85	—	2.85
—	2.90	—	2.90	—	2.90
—	2.95	—	2.95	—	2.95
—	3.00	—	3.00	—	3.00

## SPECIMEN NO.8 (continued)

Run No.8Run No.9Run No.10 $F_N = 168.16 \text{ lb.}$  $F_N = 117.41 \text{ lb.}$  $F_N = 64.78 \text{ lb.}$ 

$Q_A$	$\psi_{sR}$	$\psi_{sR}$	$\psi_{sR}$
120	--	--	--
240	--	--	15
360	--	12	73
480	--	22	772
600	10	57	--
720	35	91	
840	42	159	
960	79	283	
1080	85	--	
1200	82		
1320	99		
1440	115		
1560	135		
1680	209		
1800	225		
1920	239		
2040	266		
2160	475		
2280	--		

(REVERSE) 2.75 1011000

2.00 1011000 2.00 1011000 2.00 1011000  
2.00 1011000 2.00 1011000 2.00 1011000

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# SPECIMEN NO. 10

Material: 2S Aluminum

Control Specimen: without interface

Q <sub>A</sub>	<u>Run No. 1</u>		<u>Run No. 2</u>		<u>Run No. 3</u>	
	F <sub>N</sub> = 116 lb.		F <sub>N</sub> = 16 lb.		F <sub>N</sub> = 200 lb.	
	ψ <sub>S</sub>	ψ <sub>SR</sub>	ψ <sub>S</sub>	ψ <sub>S</sub>	ψ <sub>S</sub>	ψ <sub>S</sub>
30	28	--	22	6	--	--
60	60	--	50	5	53	7
90	96	19	--	--	--	--
120	119	19	100	4	101	1
150	152	30	--	--	--	--
180	181	26	135	21	--	--
210	211	32	--	--	--	--
240	250	39	221	30	229	29
270	271	40	--	--	--	--
300	296	42	272	31	274	29
330	323	35	--	--	--	--
360	360	44	336	35	337	46
420	--	--	393	53	--	--



First set		Second set		Third set		Fourth set	
101	101	101	101	101	101	101	101
102	102	102	102	102	102	102	102
103	103	103	103	103	103	103	103
104	104	104	104	104	104	104	104
105	105	105	105	105	105	105	105
106	106	106	106	106	106	106	106
107	107	107	107	107	107	107	107
108	108	108	108	108	108	108	108
109	109	109	109	109	109	109	109
110	110	110	110	110	110	110	110
111	111	111	111	111	111	111	111
112	112	112	112	112	112	112	112
113	113	113	113	113	113	113	113
114	114	114	114	114	114	114	114
115	115	115	115	115	115	115	115
116	116	116	116	116	116	116	116
117	117	117	117	117	117	117	117
118	118	118	118	118	118	118	118
119	119	119	119	119	119	119	119
120	120	120	120	120	120	120	120
121	121	121	121	121	121	121	121
122	122	122	122	122	122	122	122
123	123	123	123	123	123	123	123
124	124	124	124	124	124	124	124
125	125	125	125	125	125	125	125
126	126	126	126	126	126	126	126
127	127	127	127	127	127	127	127
128	128	128	128	128	128	128	128
129	129	129	129	129	129	129	129
130	130	130	130	130	130	130	130
131	131	131	131	131	131	131	131
132	132	132	132	132	132	132	132
133	133	133	133	133	133	133	133
134	134	134	134	134	134	134	134
135	135	135	135	135	135	135	135
136	136	136	136	136	136	136	136
137	137	137	137	137	137	137	137
138	138	138	138	138	138	138	138
139	139	139	139	139	139	139	139
140	140	140	140	140	140	140	140
141	141	141	141	141	141	141	141
142	142	142	142	142	142	142	142
143	143	143	143	143	143	143	143
144	144	144	144	144	144	144	144
145	145	145	145	145	145	145	145
146	146	146	146	146	146	146	146
147	147	147	147	147	147	147	147
148	148	148	148	148	148	148	148
149	149	149	149	149	149	149	149
150	150	150	150	150	150	150	150

ALLEN BRIDGES  
RESEARCH IN ITALY  
1950-1955

## SPECIMEN NO.11

Material: Copper

Control Specimen  
(without interface)

<u>Run No.1</u>			<u>Run No.2</u>		<u>Run No.3</u>	
$F_N = 20 \text{ lb.}$			$F_N = 250 \text{ lb.}$		$F_N = 200 \text{ lb.}$	
$Q_A$	$\psi_s$	$\psi_{sR}$	$\psi_s$	$\psi_{sR}$	$Q_A$	$\psi_{sR}$
30	29	--	24	4	120	--
60	48	4	--	--	240	5
90	68	14	61	7	360	5
120	85	4	--	--	480	8
150	92	6	100	4	600	10
180	117	14	--	--	720	19
210	138	28	137	--	840	28
240	154	22	--	--	960	27
270	173	28	170	15	1080	25
300	191	37	--	--	1200	40
330	211	35	205	18	1320	50
360	228	37	--	--	1440	58
390	248	44	236	22	1560	71
420	261	48	--	--	1680	87
450	281	56	--	--	1800	84

TABLE NO. 11

McFarland Paper

Control Specimen  
(Left Hand Specimen)

Run No. 1		Run No. 2		Run No. 3	
$V_H = 20 \text{ in.}$		$V_H = 20 \text{ in.}$		$V_H = 20 \text{ in.}$	
$\phi$	$\phi_{cr}$	$\phi$	$\phi_{cr}$	$\phi$	$\phi_{cr}$
20	20	20	20	20	20
40	40	40	40	40	40
60	60	60	60	60	60
80	80	80	80	80	80
100	100	100	100	100	100
120	120	120	120	120	120
140	140	140	140	140	140
160	160	160	160	160	160
180	180	180	180	180	180
200	200	200	200	200	200
220	220	220	220	220	220
240	240	240	240	240	240
260	260	260	260	260	260
280	280	280	280	280	280
300	300	300	300	300	300
320	320	320	320	320	320
340	340	340	340	340	340
360	360	360	360	360	360
380	380	380	380	380	380
400	400	400	400	400	400

## SPECIMEN NO.12

Material: A-4140 Steel

Surface Finish: 4/0 Paper

	<u>Run No.1</u>		<u>Run No.2</u>		<u>Run No.3</u>		<u>Run No.4</u>	
	$F_N = 31.875 \text{ lb.}$		$F_N = 53.38 \text{ lb.}$		$F_N = 117.41 \text{ lb.}$		$F_N = 168.2 \text{ lb.}$	
$Q_A$	$\psi_S$	$\psi_{SR}$	$\psi_S$	$\psi_{SR}$	$\psi_S$	$\psi_{SR}$	$\psi_S$	$\psi_{SR}$
120	54	--	59	10	45	--	--	--
150	--	--	--	--	53	--	58	--
240	94	4	116	16	100	--	--	--
300	--	--	--	--	122	--	105	--
360	156	13	176	28	142	1	--	--
450	--	--	--	--	180	--	164	--
480	277	72	265	75	186	4	--	--
600	--	--	365	225	228	16	231	14
720			562	269	265	58	--	--
750			--	--	270	--	283	10
840					295	60	--	--
960					345	76		
1080						92		
1200						100		
1320						149		
1440						183		
1560						267		
1680						659		



# TABLE 1

East Bay, California

Depth 0-10 feet

Depth	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Temperature	68.5	68.0	67.5	67.0	66.5	66.0	65.5	65.0	64.5	64.0
Specific Gravity	1.025	1.024	1.023	1.022	1.021	1.020	1.019	1.018	1.017	1.016
Salinity	35.0	34.9	34.8	34.7	34.6	34.5	34.4	34.3	34.2	34.1
Density	1.025	1.024	1.023	1.022	1.021	1.020	1.019	1.018	1.017	1.016
Transparency	10	10	10	10	10	10	10	10	10	10
Direction of Surface Current	SE	SE	SE	SE	SE	SE	SE	SE	SE	SE
Force of Surface Current	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Direction of Bottom Current	SE	SE	SE	SE	SE	SE	SE	SE	SE	SE
Force of Bottom Current	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Direction of Tidal Current	SE	SE	SE	SE	SE	SE	SE	SE	SE	SE
Force of Tidal Current	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Direction of Wind-Driven Current	SE	SE	SE	SE	SE	SE	SE	SE	SE	SE
Force of Wind-Driven Current	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

## SPECIMEN NO. 12 (continued)

	<u>Run No. 5</u>		<u>Run No. 6</u>		<u>Run No. 7</u>		<u>Run No. 8</u>	
	$F_H = 168.2 \text{ lb.}$		$F_H = 201.3 \text{ lb.}$		$F_H = 201.3 \text{ lb.}$		$F_H = 250 \text{ lb.}$	
$Q_A$	$\psi_S$	$\psi_{SR}$	$\psi_S$	$\psi_{SR}$	$\psi_S$	$\psi_{SR}$	$\psi_S$	$\psi_{SR}$
150	54	--	60	--	59	--	69	--
300	113	--	119	--	113	--	123	--
450	162	--	178	--	174	--	174	--
600	225	8	237	3	236	--	238	--
750	273	14	302	17	303	12	294	12
900	387	172	371	23	350	12	351	12
1050	--	--	446	30	--	22	423	22



## SPECIMEN NO.13

Material: Copper

Surface Finish: No.1 Paper

	<u>Run No.1</u>		<u>Run No.2</u>		<u>Run No.3</u>		<u>Run No.4</u>	
	$F_N = 168.2 \text{ lb.}$		$F_N = 201.3 \text{ lb.}$		$F_N = 251 \text{ lb.}$		$F_N = 64.78 \text{ lb.}$	
$Q_A$	$\psi_s$	$\psi_{sR}$	$\psi_s$	$\psi_{sR}$	$\psi_s$	$\psi_{sR}$	$\psi_s$	$\psi_{sR}$
60	45	--	26	--	--	--	--	--
120	75	7	68	--	54	--	--	--
180	116	9	111	13	--	--	--	--
240	151	10	151	6	95	--	1	--
300	--	--	190	13	--	--	--	--
360			233	12	220	10	49	--
420			255	27	--	--	--	--
480			295	24	292	4		
540			335	25	--	--		
600			380	32	378	16		
660			415	40	--	--		
720			455	38	463	38		
780			498	38	--	--		
840			542	39	546	54		



Date		Time		Location		Remarks	
Day	Month	Hour	Minute	Lat.	Long.	Alt.	Wind
1	1	10	10	30° 15' N	156° 15' W	1000	Light
2	1	10	10	30° 15' N	156° 15' W	1000	Light
3	1	10	10	30° 15' N	156° 15' W	1000	Light
4	1	10	10	30° 15' N	156° 15' W	1000	Light
5	1	10	10	30° 15' N	156° 15' W	1000	Light
6	1	10	10	30° 15' N	156° 15' W	1000	Light
7	1	10	10	30° 15' N	156° 15' W	1000	Light
8	1	10	10	30° 15' N	156° 15' W	1000	Light
9	1	10	10	30° 15' N	156° 15' W	1000	Light
10	1	10	10	30° 15' N	156° 15' W	1000	Light
11	1	10	10	30° 15' N	156° 15' W	1000	Light
12	1	10	10	30° 15' N	156° 15' W	1000	Light
13	1	10	10	30° 15' N	156° 15' W	1000	Light
14	1	10	10	30° 15' N	156° 15' W	1000	Light
15	1	10	10	30° 15' N	156° 15' W	1000	Light
16	1	10	10	30° 15' N	156° 15' W	1000	Light
17	1	10	10	30° 15' N	156° 15' W	1000	Light
18	1	10	10	30° 15' N	156° 15' W	1000	Light
19	1	10	10	30° 15' N	156° 15' W	1000	Light
20	1	10	10	30° 15' N	156° 15' W	1000	Light
21	1	10	10	30° 15' N	156° 15' W	1000	Light
22	1	10	10	30° 15' N	156° 15' W	1000	Light
23	1	10	10	30° 15' N	156° 15' W	1000	Light
24	1	10	10	30° 15' N	156° 15' W	1000	Light
25	1	10	10	30° 15' N	156° 15' W	1000	Light
26	1	10	10	30° 15' N	156° 15' W	1000	Light
27	1	10	10	30° 15' N	156° 15' W	1000	Light
28	1	10	10	30° 15' N	156° 15' W	1000	Light
29	1	10	10	30° 15' N	156° 15' W	1000	Light
30	1	10	10	30° 15' N	156° 15' W	1000	Light

SPECIMEN NO.13 (continued)

<u>Run No.4</u>		<u>Run No.5</u>		<u>Run No.6</u>		<u>Run No.7</u>		<u>Run No.7</u>	
$F_N = 64.78 \text{ lb.}$		$F_N = 117.4 \text{ lb.}$		$F_N = 168.16 \text{ lb.}$		$F_N = 201.29 \text{ lb.}$		$F_N = 201.29 \text{ lb.}$	
$\psi_{sR}$	$\psi_{sR}$	$\psi_{sR}$	$\psi_{sR}$	$\psi_{sR}$	$\psi_{sR}$	$\psi_{sR}$	$\psi_{sR}$	$\psi_{sR}$	$\psi_{sR}$
120	1	--	--	--	--	--	120	--	--
240	--	2	--	8	--	--	240	1	1
360	49	11	--	7	8	8	360	8	8
480	--	13	--	5	15	15	480	15	15
600		16	--	8	13	13	600	8	8
720		26	--	17	19	19	720	19	19
840		--	--	42	28	28	840	28	28
960				63	40	40	960	40	40
1080				81	44	44	1080	43	43
1200				--	48	48	1200	40	40
1320					72	72	1320	72	72
1440					184	184	1440	185	185
1560					246	246	1560	246	246
1680					--	--	1680	--	--

Time	Lat	Long	Alt	Temp	Wind	Clouds	Remarks
0000	12 12	158 00	1000	58	12	100	Clear
0100	12 11	158 01	1000	58	12	100	Clear
0200	12 10	158 02	1000	58	12	100	Clear
0300	12 09	158 03	1000	58	12	100	Clear
0400	12 08	158 04	1000	58	12	100	Clear
0500	12 07	158 05	1000	58	12	100	Clear
0600	12 06	158 06	1000	58	12	100	Clear
0700	12 05	158 07	1000	58	12	100	Clear
0800	12 04	158 08	1000	58	12	100	Clear
0900	12 03	158 09	1000	58	12	100	Clear
1000	12 02	158 10	1000	58	12	100	Clear
1100	12 01	158 11	1000	58	12	100	Clear
1200	12 00	158 12	1000	58	12	100	Clear
1300	11 59	158 13	1000	58	12	100	Clear
1400	11 58	158 14	1000	58	12	100	Clear
1500	11 57	158 15	1000	58	12	100	Clear
1600	11 56	158 16	1000	58	12	100	Clear
1700	11 55	158 17	1000	58	12	100	Clear
1800	11 54	158 18	1000	58	12	100	Clear
1900	11 53	158 19	1000	58	12	100	Clear
2000	11 52	158 20	1000	58	12	100	Clear
2100	11 51	158 21	1000	58	12	100	Clear
2200	11 50	158 22	1000	58	12	100	Clear
2300	11 49	158 23	1000	58	12	100	Clear

## SPECIMEN NO.14

Material: Copper

Surface Finish: 2/0 Paper

$Q_A$	<u>Run No.1</u>		<u>Run No.2</u>		<u>Run No.3</u>	
	$F_N = 64.8 \text{ lb.}$		$F_N = 117.4 \text{ lb.}$		$F_N = 168.2 \text{ lb.}$	
	$\psi_s$	$\psi_{sR}$	$\psi_s$	$\psi_{sR}$	$\psi_s$	$\psi_{sR}$
120	73	--	66	--	64	--
240	152	16	136	5	133	--
360	237	26	219	16	205	--
480	341	44	304	33	269	--
600	464	289	393	57	353	5
720	--	--	501	90	431	13
840			521	124	501	15
960			--	294	586	21
1080				873	--	31
1200				--		34
1320						37
1440						64
						--



## AL-05 11415542

1997 1414

total 5% initial costs

[illegible]

## SPECIMEN NO.14 (continued)

Run No.4 $F_N = 201.3 \text{ lb.}$ 

$Q_A$	$\psi_a$	$\psi_{sR}$
120	68	--
240	148	16
360	224	23
480	303	38
600	374	48
720	468	63
840	550	67
960	630	79
1080	--	88
1200		95
1320		119
1440		135
1560		178
1680		194
1800		218
1920		258
2040		--

Run No.5 $F_N = 231.68 \text{ lb.}$ 

$Q_A$	$\psi_a$	$\psi_{sR}$
120	77	--
240	113	14
360	228	28
480	309	37
600	383	43
720	465	54
840	543	66
960	633	85
1080	--	84
1200		96
1320		117
1440		118
1560		139
1680		155
1800		165
1920		180
2040		203
2160		235
2280		261
2400		292
2520		--

[illegible]

of 0.108 = 11%

Year	1970	1971	1972
1970	100	100	100
1971	100	100	100
1972	100	100	100
1973	100	100	100
1974	100	100	100
1975	100	100	100
1976	100	100	100
1977	100	100	100
1978	100	100	100
1979	100	100	100
1980	100	100	100
1981	100	100	100
1982	100	100	100
1983	100	100	100
1984	100	100	100
1985	100	100	100
1986	100	100	100
1987	100	100	100
1988	100	100	100
1989	100	100	100
1990	100	100	100
1991	100	100	100
1992	100	100	100
1993	100	100	100
1994	100	100	100
1995	100	100	100
1996	100	100	100
1997	100	100	100
1998	100	100	100
1999	100	100	100
2000	100	100	100
2001	100	100	100
2002	100	100	100
2003	100	100	100
2004	100	100	100
2005	100	100	100
2006	100	100	100
2007	100	100	100
2008	100	100	100
2009	100	100	100
2010	100	100	100
2011	100	100	100
2012	100	100	100
2013	100	100	100
2014	100	100	100
2015	100	100	100
2016	100	100	100
2017	100	100	100
2018	100	100	100
2019	100	100	100
2020	100	100	100
2021	100	100	100
2022	100	100	100
2023	100	100	100
2024	100	100	100
2025	100	100	100
2026	100	100	100
2027	100	100	100
2028	100	100	100
2029	100	100	100
2030	100	100	100
2031	100	100	100
2032	100	100	100
2033	100	100	100
2034	100	100	100
2035	100	100	100
2036	100	100	100
2037	100	100	100
2038	100	100	100
2039	100	100	100
2040	100	100	100
2041	100	100	100
2042	100	100	100
2043	100	100	100
2044	100	100	100
2045	100	100	100
2046	100	100	100
2047	100	100	100
2048	100	100	100
2049	100	100	100
2050	100	100	100
2051	100	100	100
2052	100	100	100
2053	100	100	100
2054	100	100	100
2055	100	100	100
2056	100	100	100
2057	100	100	100
2058	100	100	100
2059	100	100	100
2060	100	100	100
2061	100	100	100

# SPECIMEN NO.15

Material: Copper

Surface Finish: 4/0 Paper

	Run No.1	Run No.2	Run No.3	Run No.4	Run No.5
	$F_N = 201.3 \text{ lb.}$	$F_N = 168.2 \text{ lb.}$	$F_N = 117.4 \text{ lb.}$	$F_N = 168.2 \text{ lb.}$	$F_N = 117.4 \text{ lb.}$
$C_A$	$\psi_s$	$\psi_{sR}$	$\psi_{sR}$	$\psi_{sR}$	$\psi_{sR}$
120	70	--	--	--	7
240	143	--	--	9	28
360	207	6	--	13	52
480	288	--	2	17	122
600	365	14	11	30	--
720	--	1	13	36	
840		5	20	67	
960		3	--	99	
1080		6		--	
1200		11	17		
1320		22	19		
1440		31	20		
1560		40	27		
1680		57	54		
1800		64	--		
1920		--			





## SPECIMEN NO.15 (continued)

Material: Copper

Surface Finish: 4/0 Paper

Run No.6Run No.7 $F_N = 64.8 \text{ lb.}$  $F_N = 64.8 \text{ lb.}$ 

$\phi_A$	$\psi_{SR}$	$\psi_{SR}$
120	-9	8
240	2	21
360	33	82
480	--	741
600		--

## SPECIMEN NO.16

Material: 2S Aluminum

Surface Finish: No.1 Paper

Run No.1Run No.2 $F_N = 168.2 \text{ lb.}$  $F_N = 201.3 \text{ lb.}$ 

$\phi_A$	$\psi_S$	$\psi_{SR}$	$\psi_S$	$\psi_{SR}$
12	16	4	--	--
30	36	12	33	--
60	73	12	52	--
90	93	24	90	10
120	126	28	112	12
150	163	37	143	16
180	182	52	172	12
210	215	61	194	18
240	246	55	229	22
270	273	63	260	16
300	301	66	283	32
330	343	71	--	--
360	368	73		
390	395	83		
420	420	86		



DEFINITION OF SYMBOLS

- $A$  = area (square inches)  
 $D_1$  = inside diameter of specimen (inches)  
 $D_o$  = outside diameter of specimen (inches)  
 $E$  = modulus of elasticity (Youngs modulus) ( $\text{lb./in}^2$ )  
 $E_s = G$  = modulus of rigidity (shearing modulus) ( $\text{lb/in}^2$ )  
 $F_N$  = force normal to interface (normal load on specimen)  
 (pounds or kilograms)  
 $L$  = gage length or length along specimen between indicator  
 arms (inches)  
 $Q_A$  = applied torque (gram inches)  
 $R$  = radius of indicator arm (inches)  
 $r_m$  = mean radius of specimen (inches)  
 $S_N$  = normal stress at interface ( $\text{lb/in}^2$ )  
 $s_n$  = normal stress at interface ( $\text{kg/cm}^2$ )  
 $S_P$  = principal stress in specimen ( $\text{lb/in}^2$ )  
 $S_s$  = combined shear stress in specimen ( $\text{lb/in}^2$ )  
 $S_T$  = maximum tangential stress in interface due  
 to applied torque ( $\text{lb/in}^2$ )  
 $s_t$  = maximum tangential stress in interface ( $\text{kg/cm}^2$ )  
 $T_A$  = torque applied to specimen (lb. inches)  
 $\psi_c$  = calculated angle of twist for specimen  
 without interface (minutes of arc)  
 $\psi_o$  = observed angle of twist in specimen (minutes of arc)  
 $\psi_R$  = residual angle of twist in specimen (minutes of arc)  
 $\psi_s$  = observed angle of twist in specimen (micrometer drum units)  
 $\psi_{sR}$  = residual angle of twist in specimen (micrometer drum units)  
 $\Theta_R$  = apparent slip at interface (centimeters)



EXPERIMENTAL DATA

A	=	area (square inches)
$A_1$	=	initial diameter of specimen (inches)
$A_2$	=	final diameter of specimen (inches)
B	=	modulus of elasticity (pounds per square inch)
$E$	=	modulus of elasticity (pounds per square inch)
$E_1$	=	initial modulus of elasticity (pounds per square inch)
$E_2$	=	final modulus of elasticity (pounds per square inch)
F	=	force applied or load (pounds)
$F_1$	=	initial force applied (pounds)
$F_2$	=	final force applied (pounds)
$F_3$	=	force of indentation (pounds)
$F_4$	=	mean value of force (pounds)
$F_5$	=	actual stress of fracture (pounds per square inch)
$F_6$	=	actual stress of fracture (pounds per square inch)
$F_7$	=	actual stress of fracture (pounds per square inch)
$F_8$	=	actual stress of fracture (pounds per square inch)
$F_9$	=	actual stress of fracture (pounds per square inch)
$F_{10}$	=	actual stress of fracture (pounds per square inch)
$F_{11}$	=	actual stress of fracture (pounds per square inch)
$F_{12}$	=	actual stress of fracture (pounds per square inch)
$F_{13}$	=	actual stress of fracture (pounds per square inch)
$F_{14}$	=	actual stress of fracture (pounds per square inch)
$F_{15}$	=	actual stress of fracture (pounds per square inch)
$F_{16}$	=	actual stress of fracture (pounds per square inch)
$F_{17}$	=	actual stress of fracture (pounds per square inch)
$F_{18}$	=	actual stress of fracture (pounds per square inch)
$F_{19}$	=	actual stress of fracture (pounds per square inch)
$F_{20}$	=	actual stress of fracture (pounds per square inch)

BIBLIOGRAPHY

1. A.J. Coyle and H.A. Stromberg, Jr., "Elastic Behavior of Metal Interfaces," M.I.T. Thesis, 1954.
2. G.A. Tomlinson, P.L. Thorpe, and J.H. Gough, "An Investigation of the Fretting Corrosion of Closely Fitting Surfaces," Institute of Mechanical Engineers, 1939.
3. S. Timoshenko and G.H. MacCullough, "Elements of Strength of Materials," D. Van Nostrand Company, Inc., New York, 1940.
4. F.P. Bowden and D. Tabor, "The Friction and Lubrication of Solids," Oxford at the Clarendon Press, 1950.
5. M.C. Shaw and E.F. Macks, "Analysis and Lubrication of Bearings," McGraw-Hill Book Company, Inc., New York, 1949.
6. J.M. Labberton and L.S. Marks, "Marine Engineers Handbook," McGraw-Hill Book Company, Inc., New York, 1945.
7. G. Herring and J.K. Galt, "Elastic and Plastic Properties of Very Small Metal Specimens," The Physical Review, Vol. 85, March 15, 1952, pp. 1060-1061.
8. K.J. Habell and Arthur Cox, "Engineering Optics," Sir Isaac Pitman and Sons, Ltd., London, 1948.
9. J. Strong, "Procedures in Experimental Physics," Prentice Hall, Inc., New York, 1943.

REFERENCES

1. A.J. Coyne and H.A. Thompson, Jr., "Elusive Behavior at Metal Interfaces," *J. Appl. Phys.*, 1964.
2. H.A. Thompson, Jr., "The Role of the Interface in the Elusive Behavior of Metals," *Philos. Mag.*, 1965.
3. H.A. Thompson and H.A. Thompson, Jr., "The Role of the Interface in the Elusive Behavior of Metals," *Philos. Mag.*, 1965.
4. H.A. Thompson and H.A. Thompson, Jr., "The Role of the Interface in the Elusive Behavior of Metals," *Philos. Mag.*, 1965.
5. H.A. Thompson and H.A. Thompson, Jr., "The Role of the Interface in the Elusive Behavior of Metals," *Philos. Mag.*, 1965.
6. H.A. Thompson and H.A. Thompson, Jr., "The Role of the Interface in the Elusive Behavior of Metals," *Philos. Mag.*, 1965.
7. H.A. Thompson and H.A. Thompson, Jr., "The Role of the Interface in the Elusive Behavior of Metals," *Philos. Mag.*, 1965.
8. H.A. Thompson and H.A. Thompson, Jr., "The Role of the Interface in the Elusive Behavior of Metals," *Philos. Mag.*, 1965.
9. H.A. Thompson and H.A. Thompson, Jr., "The Role of the Interface in the Elusive Behavior of Metals," *Philos. Mag.*, 1965.











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